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FINAL REPORT: S-BAND MICROWAVE SYSTEM,
CONTRACT DAAK70-79-C-0171^{new}

NOVEMBER 15, 1980

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1.0 INTRODUCTION

There are, at present, two significant methods available for introducing microwave energy into a plasma. Fehsenfeld et al. Ref. 7, utilizing his number 5 cavity, claims power transfer levels of the order of 100 percent. The principal difficulty lies in the rather restricted volume and can be expected to be quite inhomogeneous. Close coupling between the plasma and the cavity is involved.

The second technique espoused by Bossisio Ref. 8 and McTaggart Ref. 9 involves the use of a slow wave structure and a loose coupling. Because of this structure, there is little difficulty in operating the discharge and very large plasma volumes have been accommodated. Claims for very high coupling efficiency are also recorded for this technique.

Both these techniques involve the use of a "CW" magnetron. No "too much" is being said about the use of waveguide plasmas at present. Such plasmas can be either the central conductor of a coaxial waveguide having either cylindrical or spherical symmetry. They could also act as the outer wall of a coaxial waveguide. The principal problem lies in the need for an auxiliary starting technique since the field intensities in a normal waveguide structure are somewhat lower than those required for breakdown when higher pressures are involved. This can be overcome by the use of a lumped parameter waveguide which is essentially a set of leaky resonant cavities in series with the plasma tube as the common central conductor. A helical close coupling to the central conductor is another technique. An alternate system that permits the coupling with acoustic waves and that admits higher electric field intensities is a pulsed magnetron.

In order to implement a specific design that introduces microwave energy into a plasma, it is first necessary to identify the medium that will comprise the plasma.

This, in a complete analysis, includes the volume, shape factor, density, and temperature. In addition, the material species in terms of ionization levels and excited levels, at least, in the case of the simpler monatomic materials must be represented.

The resultant population will then be a system of charged particles including both electrons and ions with a residual fraction of un-ionized particles. All of these members of a more complex population, are in various stages of excitation.

Such a plasma structure will exhibit characteristic responses to external stimulation at certain unique frequencies which are due to the propagation velocities and the dominant characteristic dimensions of the plasma. When the parameters of the incident energy are appropriate for these plasma resonances, there are departures from the normal operation. The various states of excitation, the relative populations and the lifetimes of the species in those states determine how the applied energy is apportioned between the various internal plasma processes. The object then becomes the identification of the initial species distribution so that certain final processes are accentuated. In the present program several of these aspects are described in the succeeding sections. This program has not addressed the optimization of the potential resultant laser because the knowledge of the particular processes such as the reaction rates of the various alkali earth halides, and their various diatomic radicals are, at present, unavailable. The necessary data for these are, however, expected to

be provided in the next stage of the program.

2.0 ESTIMATE OF CAVITY TEMPERATURES

It is important to establish the anticipated steady state temperature of the microwave cavity and also the time required to attain this equilibrium. Four reasons are involved. The first is that the cavity wall acts as the thermal environment for the quartz plasma container. The second is the establishment of the expected variation in cavity dimensions as a function of temperature. The third is the assurance of maintaining the mechanical integrity of the cavity. The fourth is the reduction in the conductivity of the cavity itself due to an increase in temperature. To this end the steady state temperature is established for a variety of power losses. The power lost is, of course, a measure of the lack of laser efficiency at the cavity itself.

The brass cavity has a total surface area of 4089 cm^2 . The cavity was painted black to approach a unity emissivity as closely as practical. The probable value for the spectral region that is effective, is 96%. This is largely due to the refractive index of the paint binder. The convective - conductive characteristics are dominated by the external gaseous surface film which is approximately 0.43cm thick. The gas film conductivity is temperature dependent and has the value:

$$2.1 \quad k = 1.92 \times 10^{-5} \sqrt{T} (1 + 2 \times 10^{-4} T) / (1 + 124/T) \text{ joules/cm sec}^{\circ}\text{K}$$

for air, T in $^{\circ}\text{K}$.

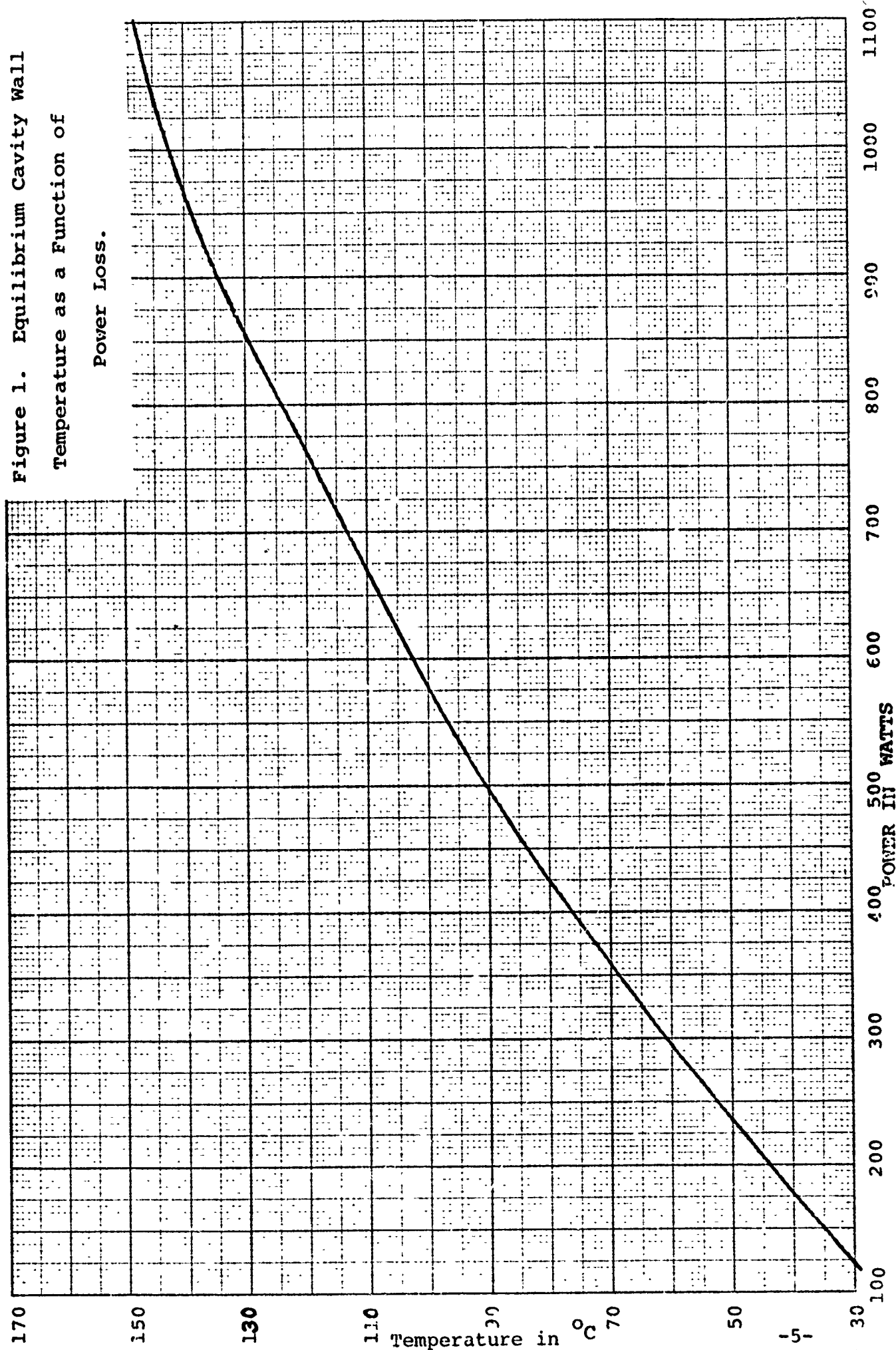
Combining the resultant power transfer with the radiative contribution from $\sigma (T^4 - T_0^4)$ results in a equilibrium temperature for the cavity which is a function of the energy being lost from the laser operation. The extreme result presumes a 0.43cm air film

and a 24°C ambient temperature T_0 . This is graphed in figure 1. The second aspect of the temperature consideration is the temperature that will be attained by the quartz vessel envelope. This is significant for several reasons. The first is for the maintenance of an adequate vapor pressure in the quartz enclosed cavity. This implies a certain minimum desired temperature. The second is the maintenance of a low enough electrical conductivity in the quartz so that a thermal runaway does not occur. This requires a maximum allowable temperature.

An estimate has been made for the temperature attained by the quartz tube when the cavity is losing power at a number of levels. These power losses correspond to the cavity temperatures shown in figure 1. The solution is, of necessity, empirical because of the complex effects due to the convective component being confined to the annular region defined by the concentric cylinders. These effects have been considered in reference 30 on which this estimate is based. The active portion of the quartz tube is approximately 71cm long and 2.5cm in diameter. This is a 580cm² surface. As an example, in free air, the quartz tube would reach about 420°C if 1000 watts were dissipated in this manner. The existence of an enclosure, which is highly reflective, surrounding the quartz, however, reduces the heat transfer to a much lower rate. The effective emissivity may be shown to be

2.2 $E = \epsilon_2 / (\epsilon_2 / \epsilon_1 + 1 - \epsilon_2)$ where ϵ_2 is the emissivity of the hot (quartz) surface and ϵ_1 is the emissivity of the cold (brass) surface. In the region of 100 to 200°C polished brass emissivities ϵ_1 is 0.055. Quartz in the range from 300 to 500°C has an emissivity

Figure 1. Equilibrium Cavity Wall
Temperature as a Function of
Power Loss.



ϵ_2 of ~ 0.78 in thickness of 2mm. Ideally, it is most desirable to minimize the effective emissivity. This permits the maximum gradient in temperature between the plasma envelope and the cavity. Any oxidation of the brass results in its effective emissivity increasing to 0.6. Improper cleansing can leave a residual coating of body oils which will be emissive at these thermal wavelengths. The radiative coupling will be increased, due to this change in the effective emissivity, from 0.055 to 0.51. Beyond 500°C the emissivity of the quartz decreases because thermal radiation at the shorter wavelengths will not be emitted in such thin layers (2mm). The detailed analysis is functionally dependent on the particular type of quartz which, combined with the other considerations, makes the analysis overly complex. We have therefore chosen several values of E the, effective emissivity, to predict only the magnitude of the quartz envelope temperature as a function of the microwave cavity surface temperature. Figure 2 is the result.

These equilibrium temperatures of the cavity are reached only after a considerable time period because of the cavity mass. This is about 9.8 Kilograms of brass. Since the heat capacity of the brass is $0.369 \text{ joules}/^{\circ}\text{C}$, the heat capacity of the entire cavity is $3.6 \times 10^3 \text{ joules}/^{\circ}\text{C}$. It is evident that the rate of temperature increase, even on the assumption that the entire 1200 watt input power was being transferred in to radiation, conduction, and convection, would not result in equilibrium in less than $\frac{1}{2}$ hour. Figure 3 shows the initial rate of temperature increase.

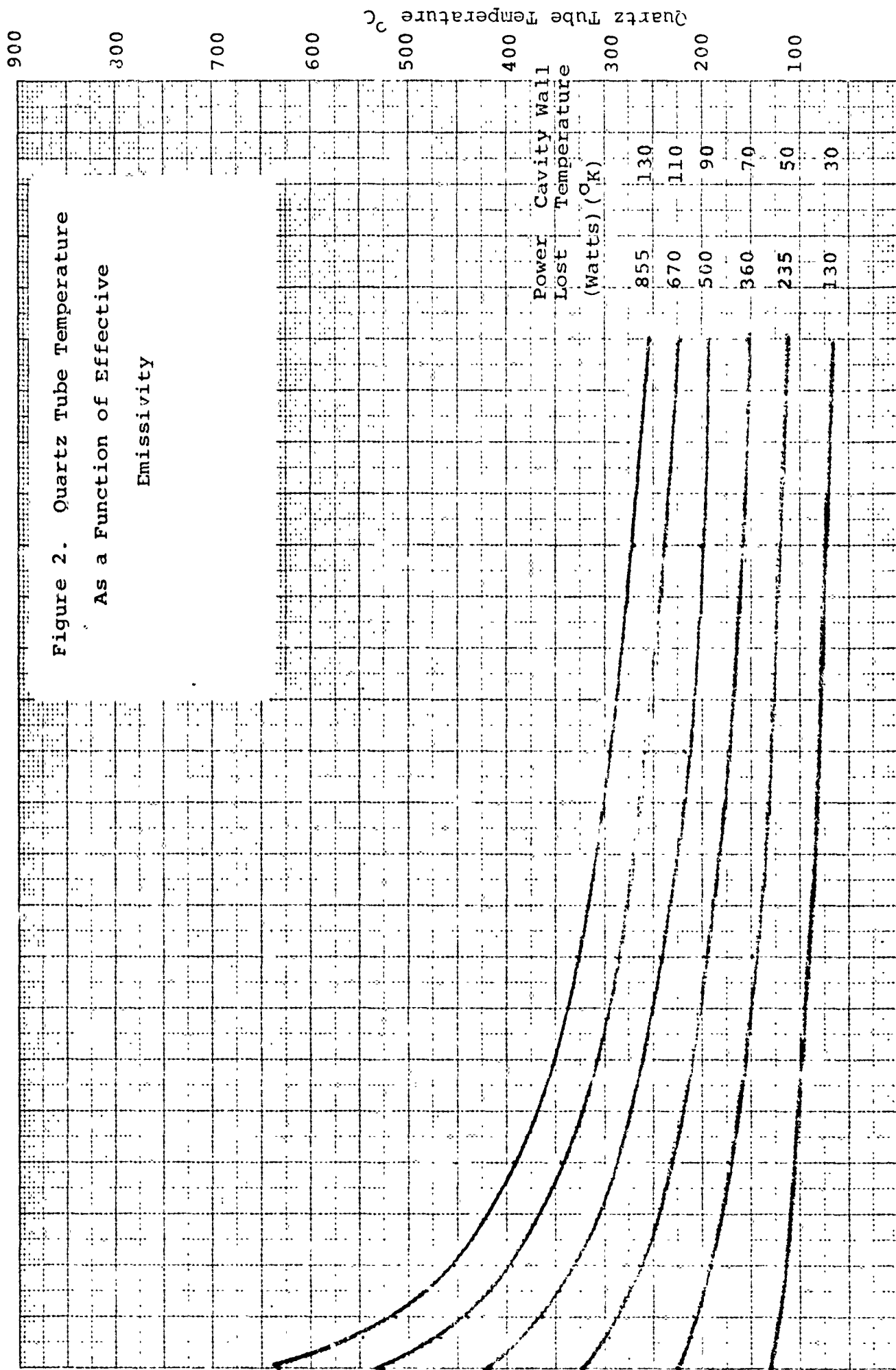
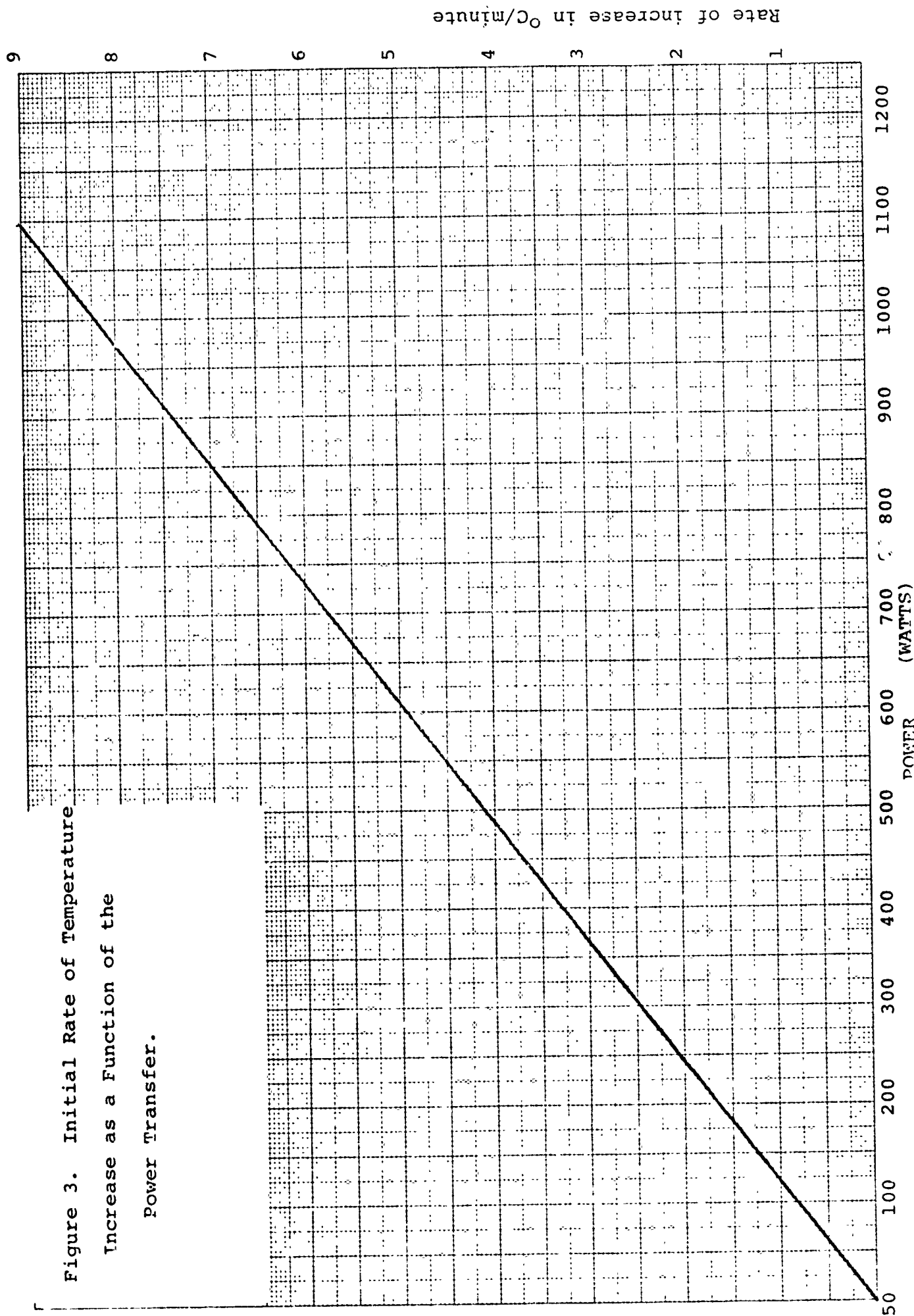


Figure 3. Initial Rate of Temperature

Increase as a Function of the

Power Transfer.



3.0 EQUILIBRIUM CHARGE DENSITY IN PLASMA

The determination of the propagation constant of a plasma requires a knowledge of the charge densities encountered. This quantity can be estimated from the Saha Equation for the specific atomic or molecular species involved at equilibrium. We have been using the form:

$$3.1 \quad \log_{10} k = \log \left(\frac{\epsilon^2}{1 - \epsilon^2} \right) P \text{ (atm)} = \left(-5044 \frac{V_i}{T} + \log \frac{\omega_i \omega_e}{\omega_a} - 6.491 \right)$$

Where V_i is the ionization energy in electron volts

T temperature in degrees kelvin

ω statistical weights of

atoms (ω_a)

ions (ω_i)

electrons (ω_e) = 2

P pressure in atmospheres

ϵ the equilibrium degree of dissociation

k the equilibrium constant

Note that:

$n_o \epsilon = n_e$ electrons/cm³ where

$LP = n_o$ particles/cm³ and

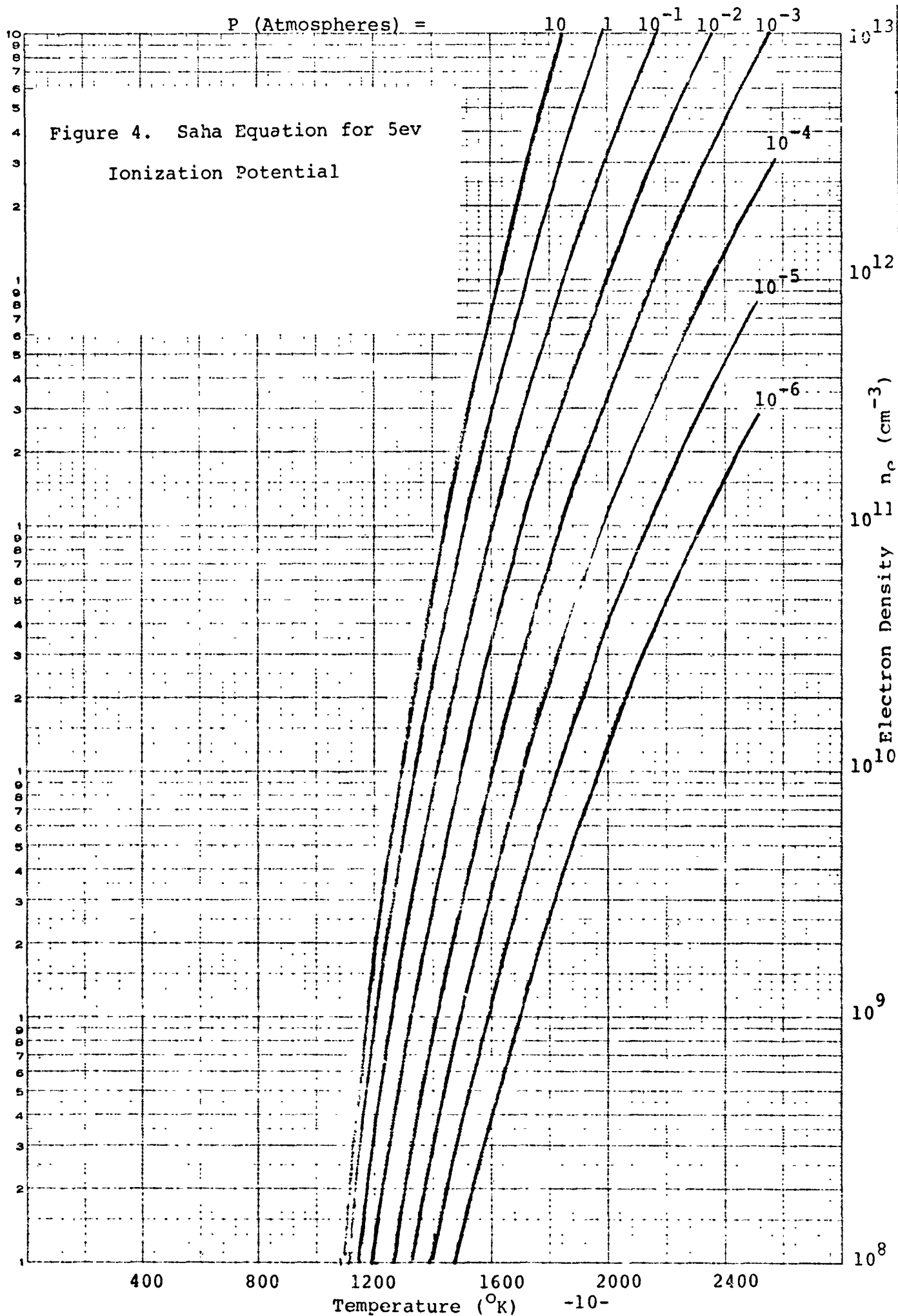
L = Loschmidts' number

This equation has been programmed onto a TI59 program card to allow a convenient population estimate as a function of temperature.

See Appendix I for format. Any need for a more detailed energy level populations of the excited states can be introduced by the utilization of the analytic techniques suggested in Ref. 1-3. Figure 4 is representative of the results obtained. The particular case

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shown is for a 5ev ionization energy with the statistical weights $\omega_1 = 2$, $\omega_a = 1$, $\omega_e = 2$. Each curve corresponds to a constant pressure condition. The units are in atmospheres.

From that it is clear that purely thermal conditions would require gas temperatures that are too extreme to produce a significant electron density. Reasonable temperatures, however, could provide an adequate initial electron density seeding for the micro-wave plasma.

4.0 VAPOR PRESSURE

The vapor pressure of magnesium was computed from the data of Kelly (Ref. 24). This was obtained so that an evaluation of the conditions of Frayne's experiment, Ref. 25, could be made. Equation 1 represents the functional form for the pressure P, in atmospheres of the crystal to gas transition.

$$4.1 \quad -R \ln P = \frac{36,560}{T} + 2.83 \log T + 6.65 \times 10^{-4} T - \frac{3.39 \times 10^4}{T^2} - 36.74$$

where R is 1.9869 calories/degree Kelvin

T is in degrees kelvin. This is valid for the temperatures up to the melting point, 922° kelvin, for magnesium.

For the liquid to gas transition the relation has the form of equation 2.

$$4.2 \quad -R \ln P = \frac{49600}{T} + 23.0 \ln T - 103.58T.$$

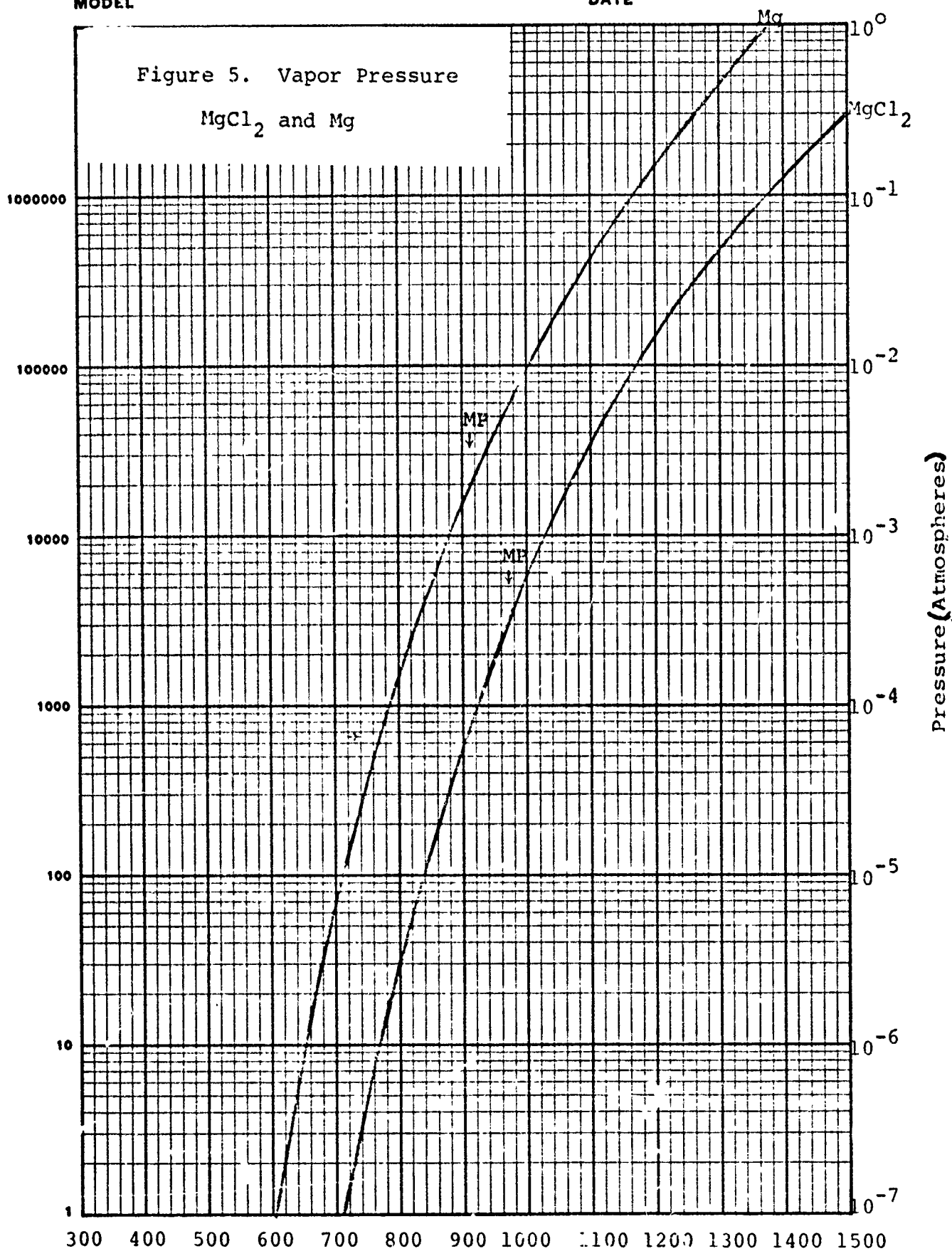
These equations were used to present the data in a graphic form in figure 5. The vapor density may be derived from these values. This is graphed in Figure 6. To the precision of the graphed data, there is little difference in the liquid-gas and solid-gas formulations.

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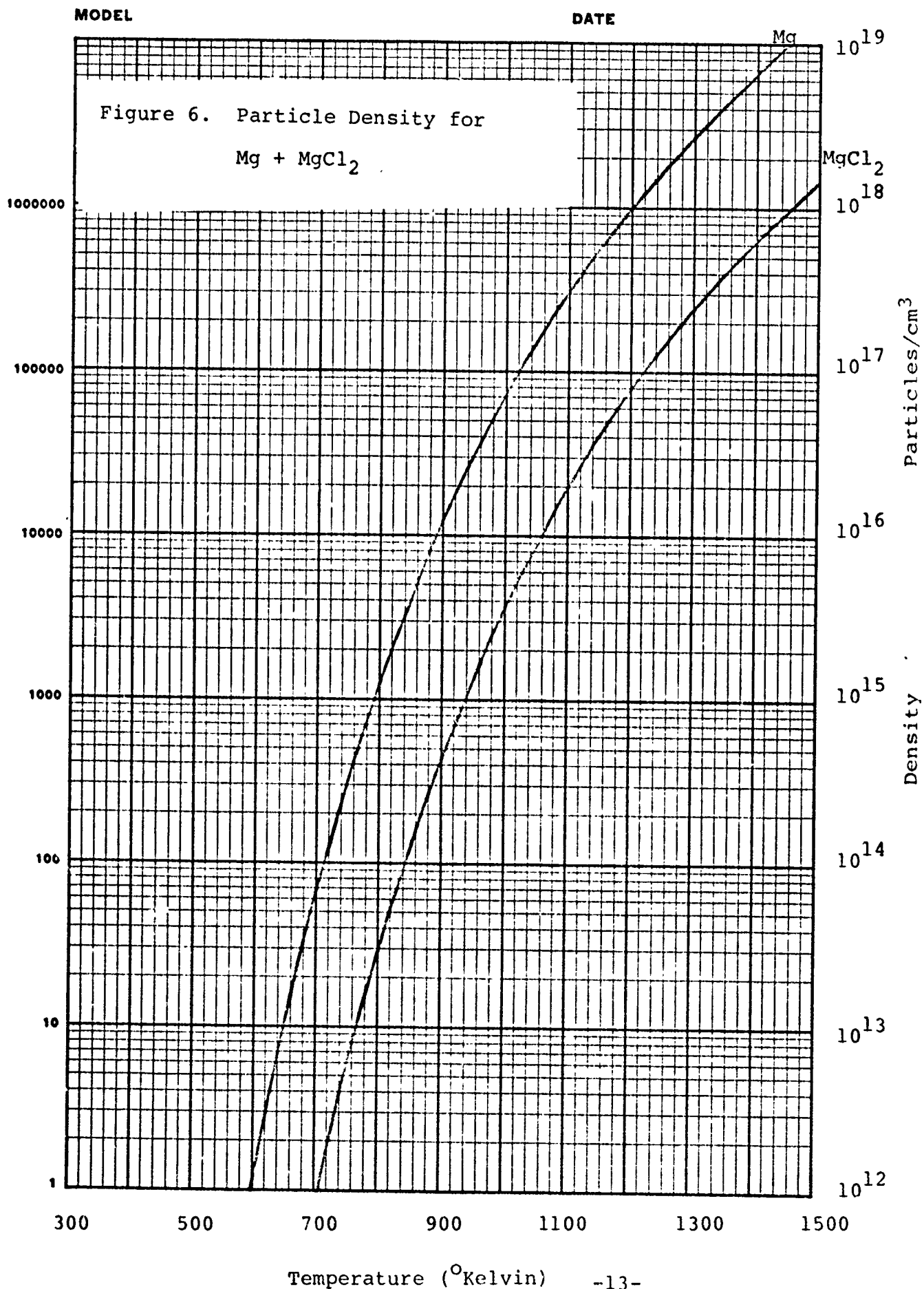
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Figure 5. Vapor Pressure
 MgCl_2 and Mg



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The difference between the two results is only as low as 600° kelvin. Confirmation is found in later work at the lower temperatures Ref. 26.

The heat of fusion of the magnesium is about 2160 calories/mole. The magnesium halides are the compounds of most interest in the present study. In the case of the magnesium halides the heat of fusion is somewhat greater so that it is to be expected that the disparity between the extrapolation of a measured liquid-gas vapor pressure curve will result in values for the halide which are higher than will be found in experiment. MgCl_2 is the only halide vapor pressure curve that is tabulated in the literature available at this establishment. It is due to Kelly Ref. 24 and is included in figure 5 and 6. The magnesium bromide should not depart very much from this curve since the heat of fusion of both MgBr_2 and MgCl_2 are similar, 8300 to 8100 calories/mole. In addition, the melting points are virtually identical 984° to 985° Kelvin. No data is available on the boiling point of MgBr_2 but, in the absence of better data, it may be assumed that the melting temperatures, boiling temperatures and critical temperatures are related through the use of Guldberg's Rule and the principle of corresponding states. Ref. 27, P238. Since the halides are a homologous series one may expect the critical pressures to form a trend based on the molecular weight.

BaCl_2 , is also a (II-VII) compound, which has a boiling point, 1560°C . This is even higher than MgCl_2 , 1412°C . With such a high boiling point it would be difficult to expect a vapor pressure in the anhydrous BaCl_2 which exceed the MgCl_2 . It has been observed

by Dr. Bramley that the anhydrous form of BaCl_2 under the activation of a 1KW microwave source results in a radiant discharge which includes all the well known band structure and relative intensities of the BaCl molecule. This discharge exhibited a greenish white color and included both the $^2\Sigma \rightarrow ^2\Sigma$ and $^2\Pi \rightarrow ^2\Sigma$ spectral band systems. Since her spectrographic equipment range did not extend beyond 0.76 microns it was not possible to ascertain the presence of $^2\Pi \rightarrow X^2\Sigma$ from 0.8421 to 0.0908 microns. Based on her previous postulate that the only difference between the strong emission in the flame excited sodium d lines as compared to the pure microwave excitation of hot sodium chloride was the presence of the water vapor product of the oxyhydrogen torch used. She tentatively used the hydrate form $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ in an enclosed chamber in the microwave cavity. The result was a marked change in the intensity distribution of the spectral band system with the overall discharge changing to a brilliant green. A spectral evaluation indicated a virtually complete suppression on a relative basis of the $^2\Sigma \rightarrow ^2\Sigma$ bands and also the relative suppression of the system of ionized Ba lines. Since the heating of the hydrate barium chloride does not result in the vaporization of the barium chloride at a low temperature but, rather, a simple driving off of the water of crystallization it would be suspected that the introduction of water vapor with the anhydrous BaCl_2 would lead to the same results. Dr. Bramley found this to be the case. This established the existence of a quenching mechanism in 1963, that would be beneficial to the populating of metastable state. In the extension of this present study, it is anticipated that the quenching mechanism that appears successful in the

$\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ will be found to be effective in the $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ charge for the microwave laser cavity.

5.0 SOME ESTIMATES ON THE DIATOMIC SPECIES OF INTEREST

In the process of establishing reactions rates it will be necessary to identify the characteristics of some of the species that will be encountered in the plasma. This section is a partial collection of some of the subsets of the magnesium halides for the convenience of further work.

Bond strengths have been given for the diatomic molecule possibilities in this group in Ref. 28. They are present in table 5.2A in Kilocalories per mole at 25°C . (298.1°Kelvin). The bond lengths for the symmetrical members are also tabulated in table 5.2B as presented in Ref. 27. No data is available to us for the remaining potential pairs. From the values assigned for the atomic and ionic radii, however, Table 5.2C an estimate can be made of the bond lengths which is simply the sum of the positive and negative radii of the components of the diatomic molecule. The magnitude of the error in such a simplistic assumption is illustrated in the comparison table 5.1 for the known cases.

Error in the Bond Length Predictions

Table 5.1

<u>Molecule</u>	<u>Listed Values</u>	<u>Estimated (table 2C)</u>	<u>Disparity</u>
Mg_2	3.197	3.198	-0.001
F_2	1.417	1.418	-0.001
Cl_2	1.988	2.078	-0.090
Br_2	2.290	2.348	-0.058
I_2	2.662	2.698	-0.036

TABLE 5.2a.
BOND STRENGTHS OF THE DIATOMIC SPECIES
(Kilocalories/mole) (25°C)

	Mg	F	Cl	Br	I
Mg	8	105.5	89	75	68
F		37	59.9	55.9	67
Cl			58	52.3	50.5
Br				46.34	42.8
I					36.50

TABLE 5.2b.
Bond Length (Å)

	Mg ⁰	F ⁻	Cl ⁻	Br ⁻	I ⁻
Mg ⁰	3.197	2.15	2.63	2.78	3.02
F ⁺	-	1.417	1.60	1.72	1.83
Cl ⁺	-	1.89	1.988	2.20	2.31
Br ⁺	-	2.04	2.23	2.290	2.46
I ⁺	-	2.28	2.47	2.59	2.662

TABLE 5.2c.
Radii, Atomic and Ionic (Å)

	-1	0	+1	+2	+5	+7
Mg	-	1.598	0.82	0.66	-	-
F	1.33	0.68	-	-	-	0.08
Cl	1.81	0.97	-	-	0.34	0.27
Br	1.96	1.13	-	-	0.47	0.39
I	2.20	1.35	-	-	0.62	0.50

On the assumption that errors not significantly at odds with those presented we assume the remaining values for the other diatomic possibilities in Table 5.2B.

6.0 ESTIMATE OF THE ELECTRON TEMPERATURE

Von Engle and Steenbeck developed a method of estimating the electron temperature in a positive gas column. The analysis is dependent on the assumption that the mean free path of the electrons is much smaller than the diameter of the tube.

Analytically, the equation has the form:

$$6.1 \quad \left(\frac{X}{A}\right)^{\frac{1}{2}} e^{A/X} = BC^2 p^2 R^2 \quad \text{where,}$$

$$X = T_e/V_i \quad A = 1.1606 \times 10^4 \text{ degrees kelvin/electron volt}$$

$$B = 1.16 \times 10^4$$

V_i = ionization potential

p = pressure in mm of mercury

R = tube radius in cm

C = a constant for the particular gas and is derived from the relation

$$6.2 \quad C = \left(a V_i^{\frac{1}{2}} / \mu^+ p \right)^{\frac{1}{2}}$$

where $a = S/(V - V_1)$ (ions/cm³mmHg·eV), S = differential ionization coefficient (ions/cm³mmHg). The mobility μ^+ is in cm/sec volt cm.

We have presented this function in figure 7.

The pertinent values for some of the gases that can be used are given in table 3. Thus for Argon at a pressure of 1.0mmHg in a 1cm radius tube processes of diffusion to the wall will balance the electron production process at

$$CpR = 0.034 \text{ which results (figure 7), in}$$

$$T_e/V_i = 1100$$

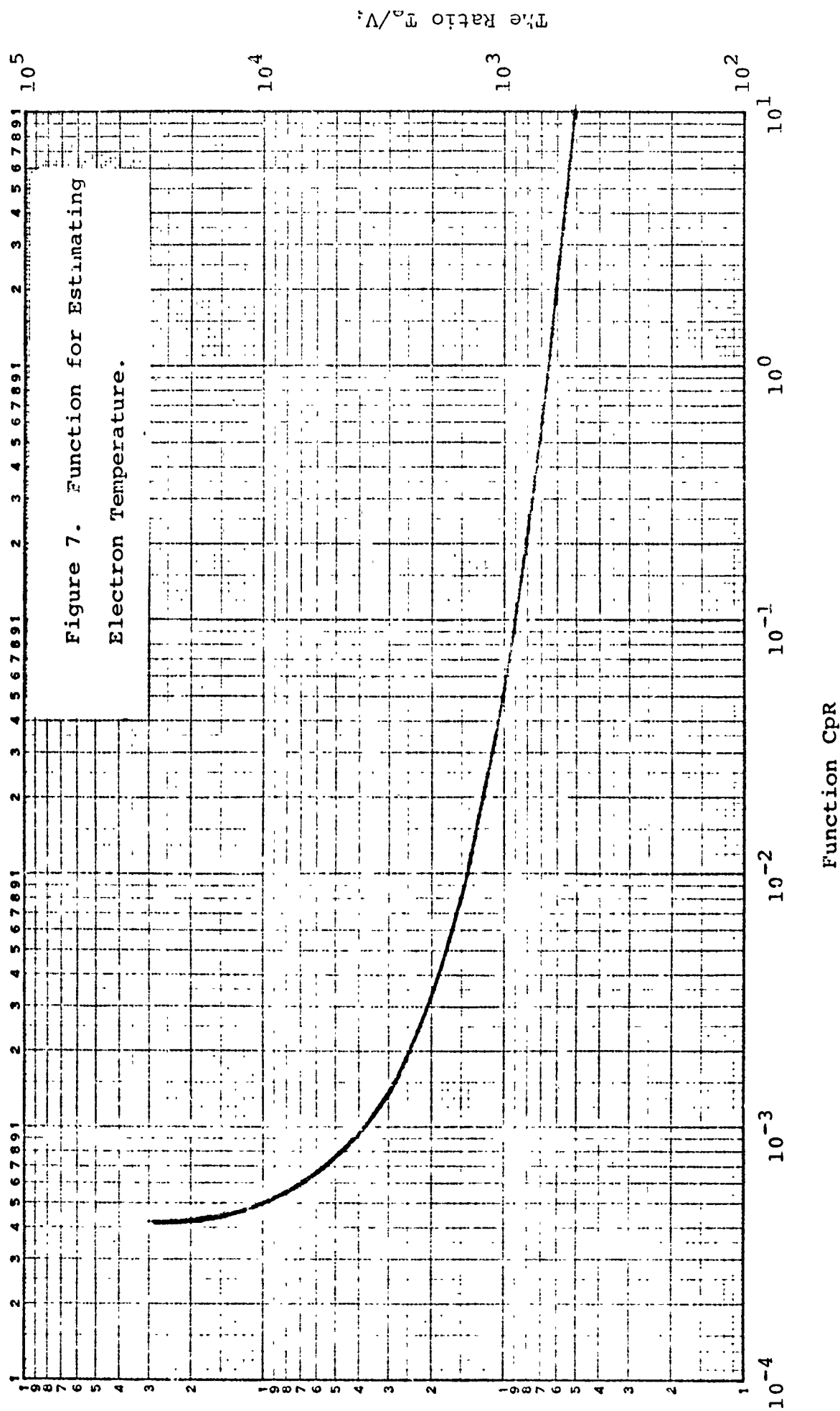
Therefore for argon $T_e \sim 17,335^\circ \text{Kelvin}$.

TABLE 3.

<u>Gas</u>	<u>Vi (ev)</u>	<u>Metastable State (ev)</u>	<u>C*</u>	<u>C**</u>
He	24.58	19.8	0.0039	3.9×10^{-3}
Ne	21.56	16.62	0.0059	6.5×10^{-3}
A	15.76	11.55	0.053	3.4×10^{-2}
Kr	14.00	9.91	--	5.1×10^{-2}
Xe	12.13	8.32	--	
N ₂			0.095	
H ₂			0.0135	

* Von Engle and Steenbeck (See P. 240 Cobine, Gaseous Conductors, Dover 1958.)

** Calculated from the newer transport property values (normalized to He).



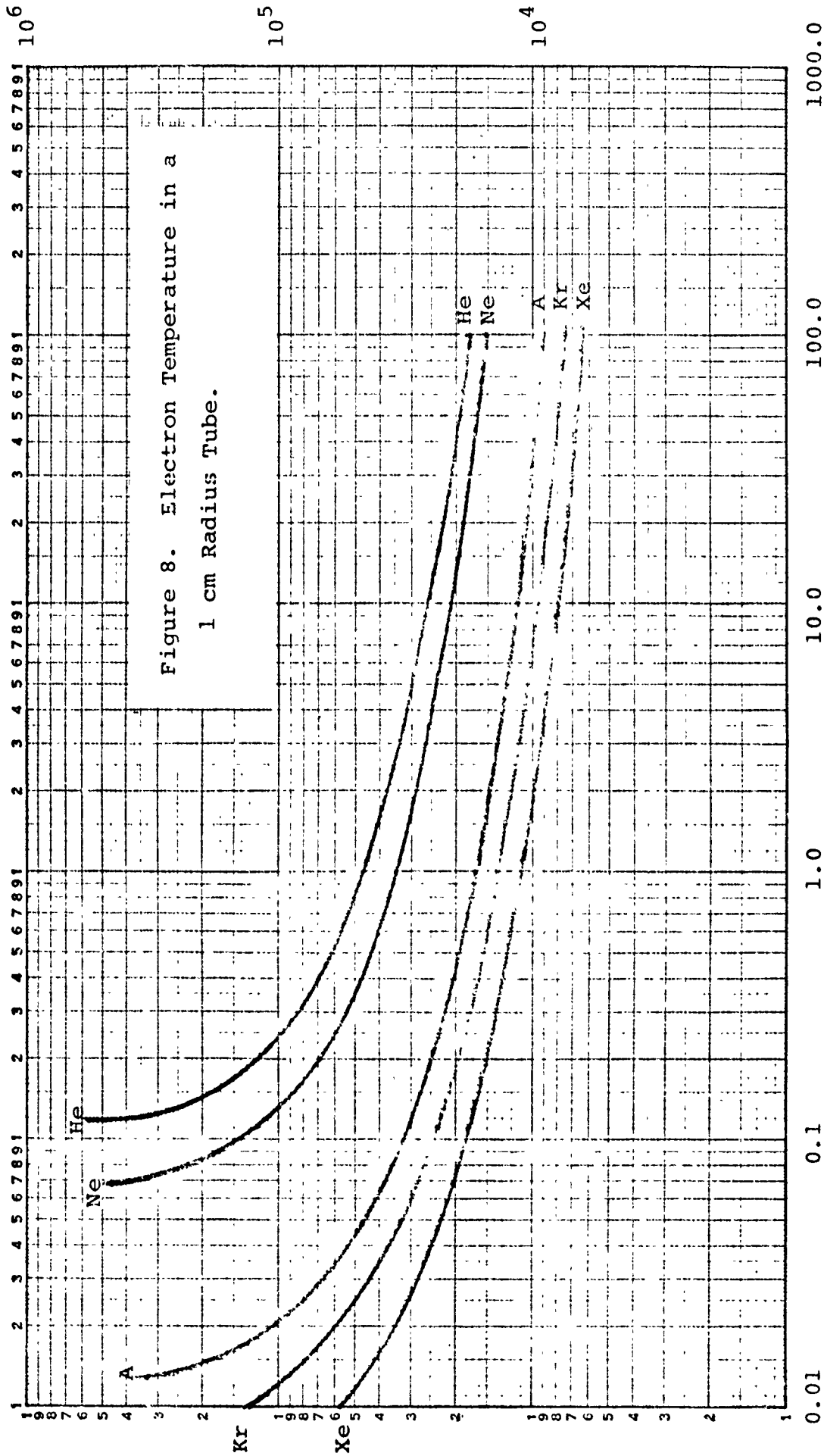
The constant C is a function of the gas temperature, T_g , through the mobility-pressure product. Therefore, if the mobility μ_o^+ , and pressure p_o at the room gas temperature $T_o(^{\circ}\text{K})$ are known the mobility μ_g^+ and pressure p_g at the gas temperature $T_g(^{\circ}\text{K})$ may be obtained. This leads to the simplified relation

$$6.3 \quad \mu_g^+ p_g = \mu_o^+ p_o \frac{T_g}{T_o}.$$

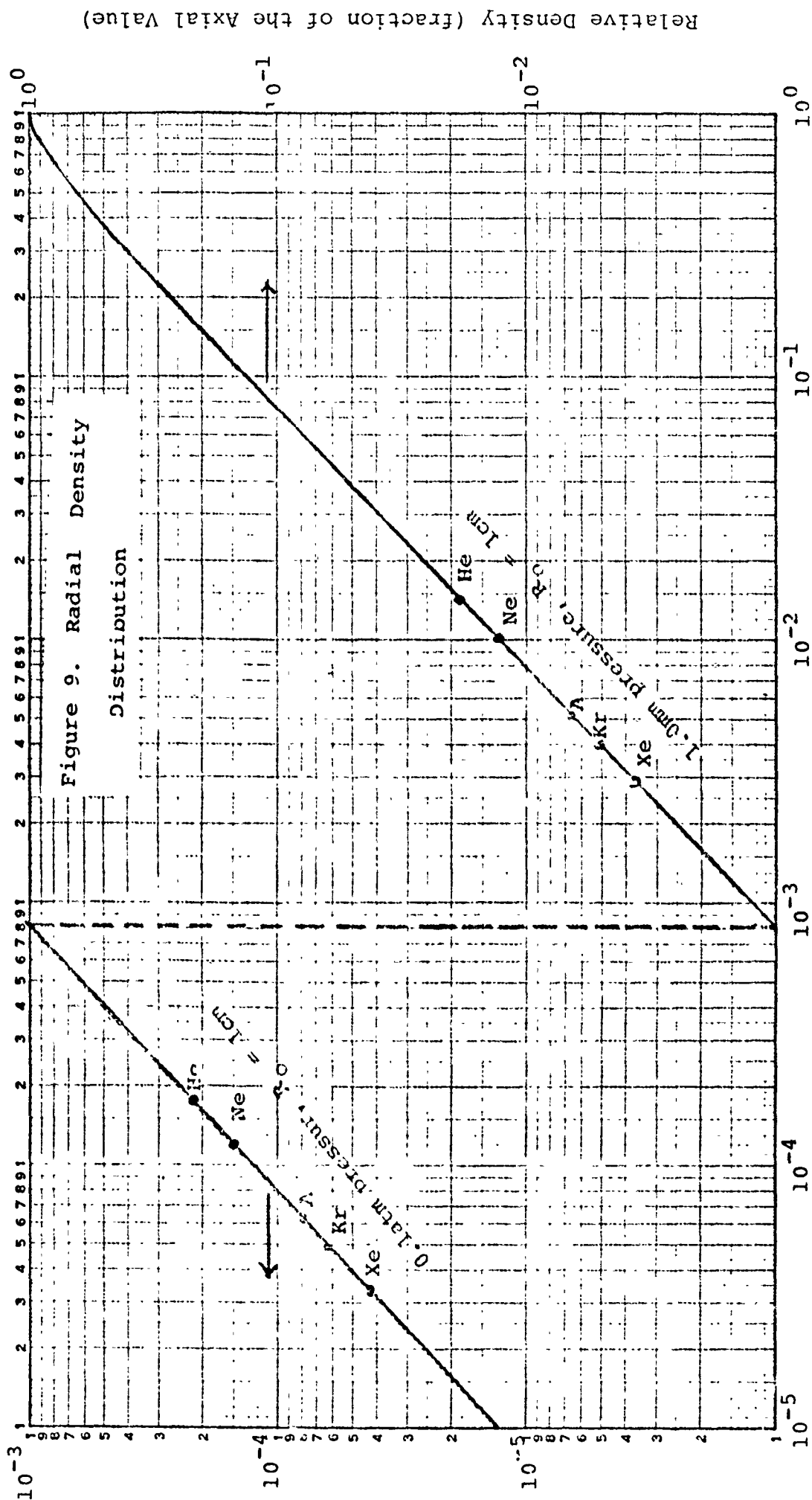
From the equation 6.2 for C it is clear that if C_o is defined as the value of the constant at room temperature then C at temperature T_g can be written as a function of temperature alone i.e.

$$6.4 \quad C = C_o (T_o/T_g)^{1/2}.$$

The gas temperatures of the order of room temperature the values of C can be used directly. Higher gas temperatures will be encountered at the higher pressures and would require an appropriate decrease in the value of CpR . This quantity reaches its minimum value at about 4.4×10^{-4} when $T_e/V_i = 23,000$. A maximum electron temperature for a particular radius tube, at a specific minimum pressure and for a particular material is then predicted on the basis of the relation graphed in Figure 8. These electron temperatures were developed for the noble gases in a 1cm tube for a room temperature gas situation. Higher gas temperatures have little effect on the electron temperature at the higher pressures. If however, the temperature is raised at the lower pressures a marked increase in the electron temperature will be obtained. To illustrate, increasing the gas temperature from 277°K to $1188^{\circ}\text{Kelvin}$ (895°C) decreases C by a factor of 2. This results in helium at 1mm pressure having an electron temperature of $60,500^{\circ}\text{Kelvin}$ instead of $41000^{\circ}\text{Kelvin}$. The same gas temperature change at 100mm of Hg



Pressure P (mm Hg)



pressure would change the helium electron temperature from 19,000°K to 20,500°K. The pressure of the fill gas is important in establishing the average energy of the electrons with respect to the dissociation level that corresponds to the process $\text{Mg}(\text{halide}) \rightarrow \text{Mg}^* + (\text{halide})_2$.

7.0 COMPUTATION OF THE RADIAL DENSITIES

It has been shown that when the electron mean free path is short compared to the tube radius, the radius density distribution will correspond to that of the zeroth order Bessel function J_0 .

7.1 $n_r^+ = n_0^+ J_0(2.404r/R)$. n_0^+ is the number of positive ions per cm^3 on the axis of the quartz plasma tube and n_r^+ is the number of positive ions per cm^3 at the radius r less than the inner radius R of the plasma tube. The positive ions follow this distribution and are shown as a function of δ/R_0 where $\delta(\text{cm})$ is the distance from the wall of the tube. The equivalent of 1 mean free path from the wall of the tube for the ionic gas atoms for two pressure regimes are shown in Figure 9. Since the conditions determining the diffusion of ions and electrons is ambipolar (Ref. 29, P.243) the concentrations of ions and electrons are equal at all points $n^- = n^+$ the electron density distribution has the same functional form. The refractive index of the plasma is dependent on the charge density. This predicts the gradient of the refractive index that will be encountered by the entering microwave.

8.0 PLASMA RESISTIVITY

The plasma resistivity is also a function of the electron density and the electron temperature. The relationship is a modification of the Lorentz gas approximation.

$$8.1 \quad \rho_L = 3.8 \times 10^3 \frac{Z \ln \Lambda}{T^{3/2}} \quad \text{ohm cm}$$

A correction is required for $Z = 1$ which is expected to be the primary situation, Z is the degree of ionization, the change is in the constant and the equation becomes

$$8.2 \quad \rho = 6.53 \times 10^3 \ln \Lambda / T^{3/2} \quad \text{ohm cm.}$$

The extended studies Ref. 17 to 22 confirm, at least, the magnitude of this correction. Figure 10 presents the region of interest and Appendix 4 gives the program used.

9.0 RESISTIVITY MODELS FOR THE PLASMA

The range of resistivities pertinent to the present problem varied from 10^{-2} to 12×10^{-2} ohm cm for the electron temperatures and densities of interest. It had been expected that a liquid load would be able to represent this range. It was found, however, that at the frequency of the microwave 2.45×10^9 Hz even high molal solutions of sodium chloride still had too high a resistivity, table 9.4.

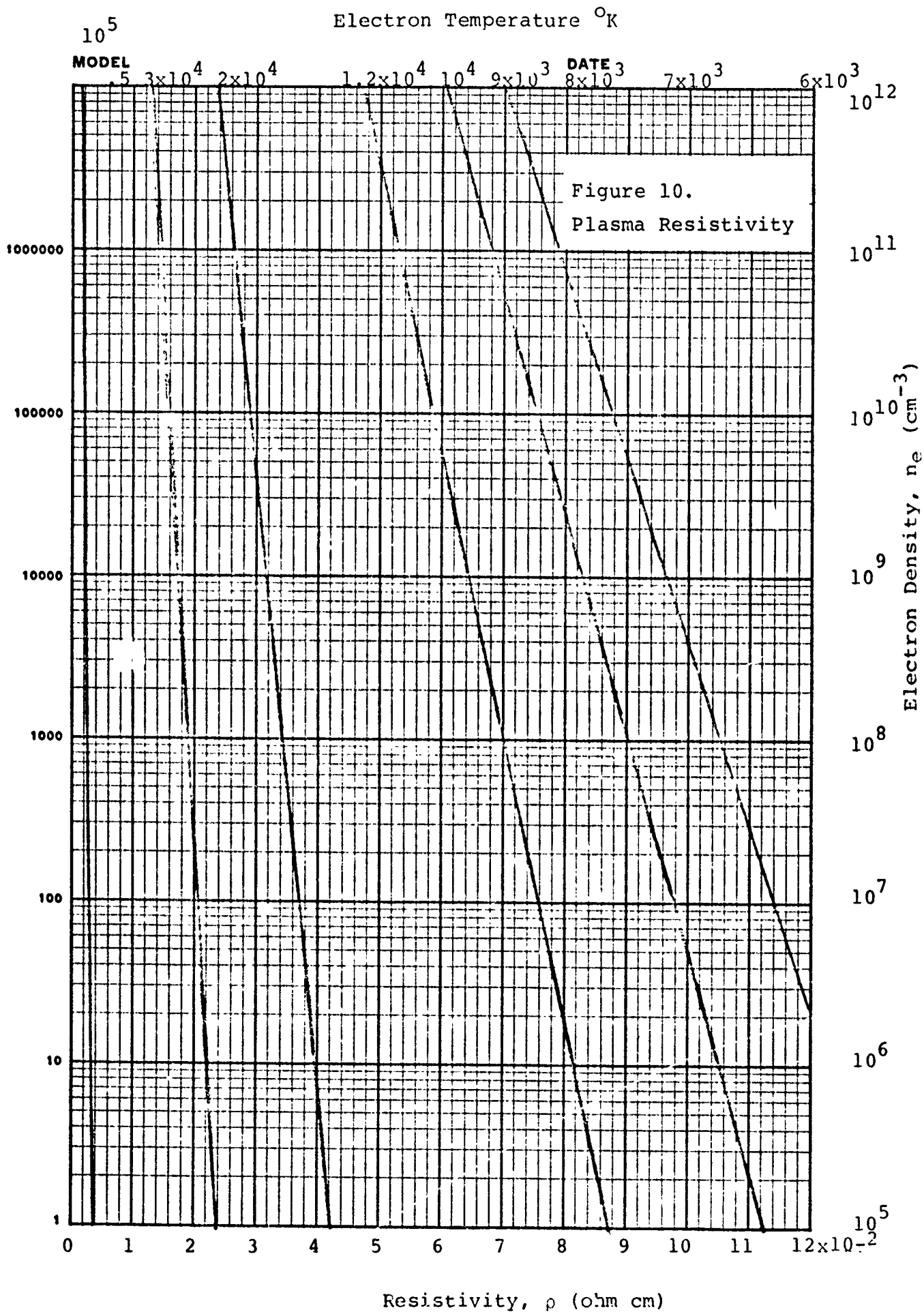
Table 9.4

Resistivity of Sodium Chloride Solutions,
ohm cm, at Microwave Frequencies

Frequency	Molality	.1	.3	.5	
3×10^8 Hz		101	35	22	
3×10^9 Hz		33	19.9	14.3	
10^{10} Hz		5.9	5.72	5.6	ohm cm

Spectoscopic Graphite electrodes were found to be .001 ohm cm which is a bit too low. The #3 pencil "lead" was found to be 0.062 ohm cm, right at the center of the range, and the H pencil "lead" was found to be 0.030 ohm cm. Both of these materials

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maintain their integrity at high temperatures and correspond to realistic values in the range of interest. These were used as test loads in the cavity.

10.0 SKIN DEPTH

The opacity of the plasma tube to the microwave is a function of the physical thickness δ of the plasma and the frequency ν_0 of the applied microwaves. If the applied frequency is much less than the collision frequency ν_c the relation

10.1 $\delta_0 = (\rho/\pi\nu_0\mu_0)^{1/2} = 5.033 \times 10^3 (\rho/\nu_0)^{1/2}$ cm where μ_0 is the permeability of free space, $4\pi \times 10^{-5}$ hy/cm, see Ref. 31. The value of δ_0 is that depth of the resistive medium at which the attenuating portion of the propagation constant reduces the field intensity to e^{-1} of its initial value. The applied frequency is 2.45×10^9 Hz so that δ_0 based on these premises is

10.2 $\delta_0 = 0.102 \times (\rho)^{1/2}$ cm, ρ resistivity (ohm cm)

The resistivity range anticipated will lie between 10^{-2} and 2×10^{-1} ohm cm which predicts values of $\delta_0 = 10^{-2}$ to 4.6×10^{-2} cm for the usual skin effect values. When the phase velocity becomes imaginary, as it will when ν_0 is less than the plasma frequency ν_p , the amplitude will decrease by e^{-1} in the depth δ_i

10.3 $\delta_i = \frac{c}{2\pi \nu_p} / (1 - (\nu_0/\nu_p)^2)^{1/2}$ cm.

Since the plasma frequency may be written as a function of the electron density n_e , Section 13, this becomes,

10.4 $\delta_i = 5.323 \times 10^5/n_e^{1/2} (1 - 7.46 \times 10^{10}/n_e)^{1/2}$.

Figure 11 represents these two skin depth values at the frequency that is being applied. The larger value of δ is to be taken. No magnetic field is considered in this case. You will note that the skin depth, under these circumstances, becomes a function of the radial dimension of the plasma. This is due to the radial variation in the electron density n_e .

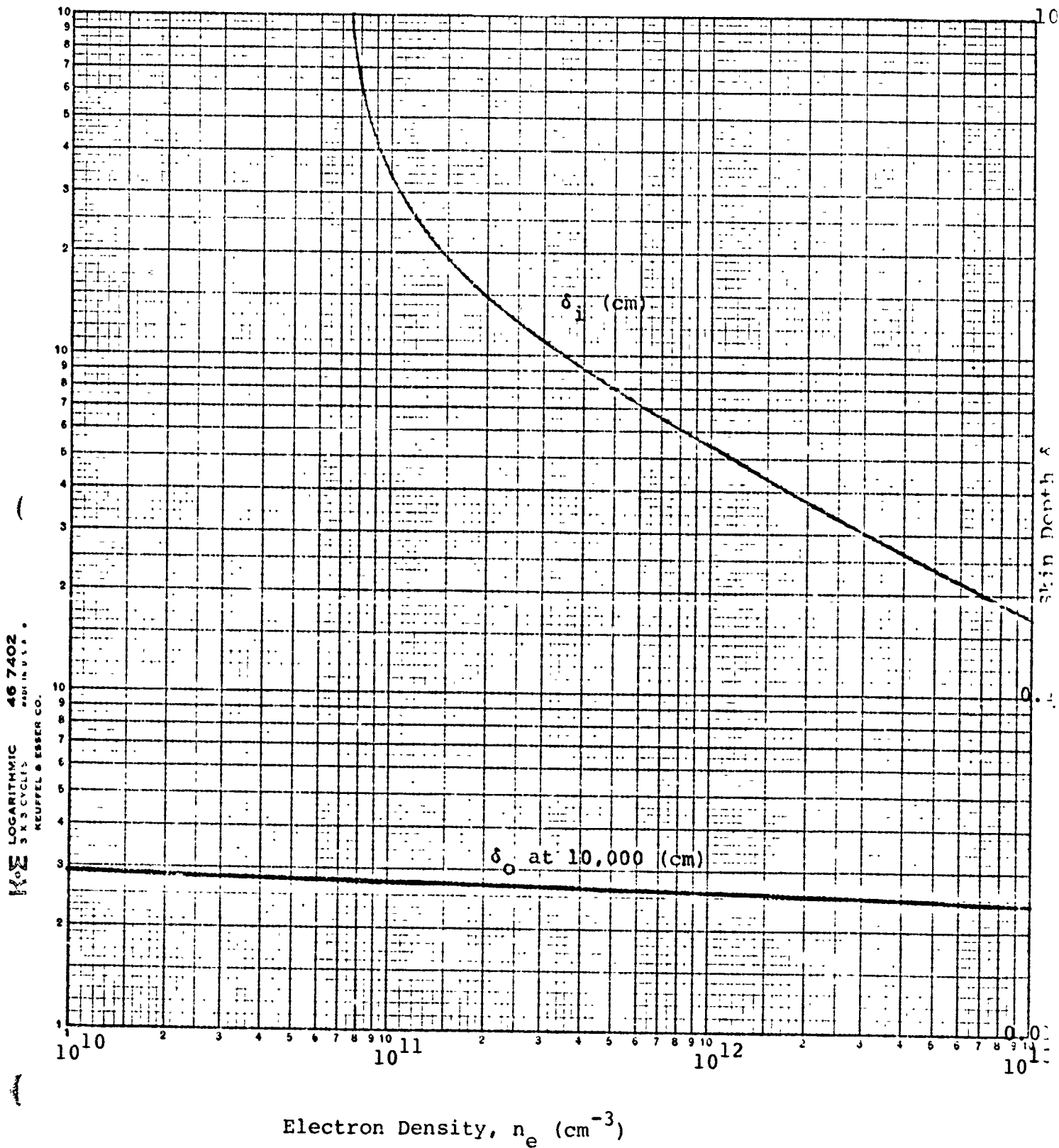
11.0 EXPECTED VALUES OF Q

The values of Q for the TE_{11n} and TM_{01n} modes were calculated from the known relation given in Appendix 3.

n is defined as the number of $\frac{1}{2}$ wavelengths along the axis of the cavity. The result, for a 10.82cm diameter cavity with a cavity resistivity of $\rho = 7 \times 10^{-6}$ ohm cm corresponding to the brass cylinder chosen, are shown in figure 12 for the TE_{11n} and in figure 13 for TM_{01n} . In these figures the value of Q is shown as a function of the ratio of cavity length to diameter with n as the parameter associated with each of the nine solid curves. Several specific free space wave lengths are overlayed as dashed curves. The anticipated wave length is 12.28 cm. In order that the variation with frequency might be shown, figure 14 was developed with n and frequency as parameters and Q and L/D again as coordinates.

The values predicted for the Q of such a brass cylinder should have been of the order of 18,500 for the TM_{016} mode and about 22500 for the TE_{119} mode. The results of measurements for the empty cavity are shown in table 11.5.

Figure 11. Skin Depth at 2.45
Kilomegahertz.



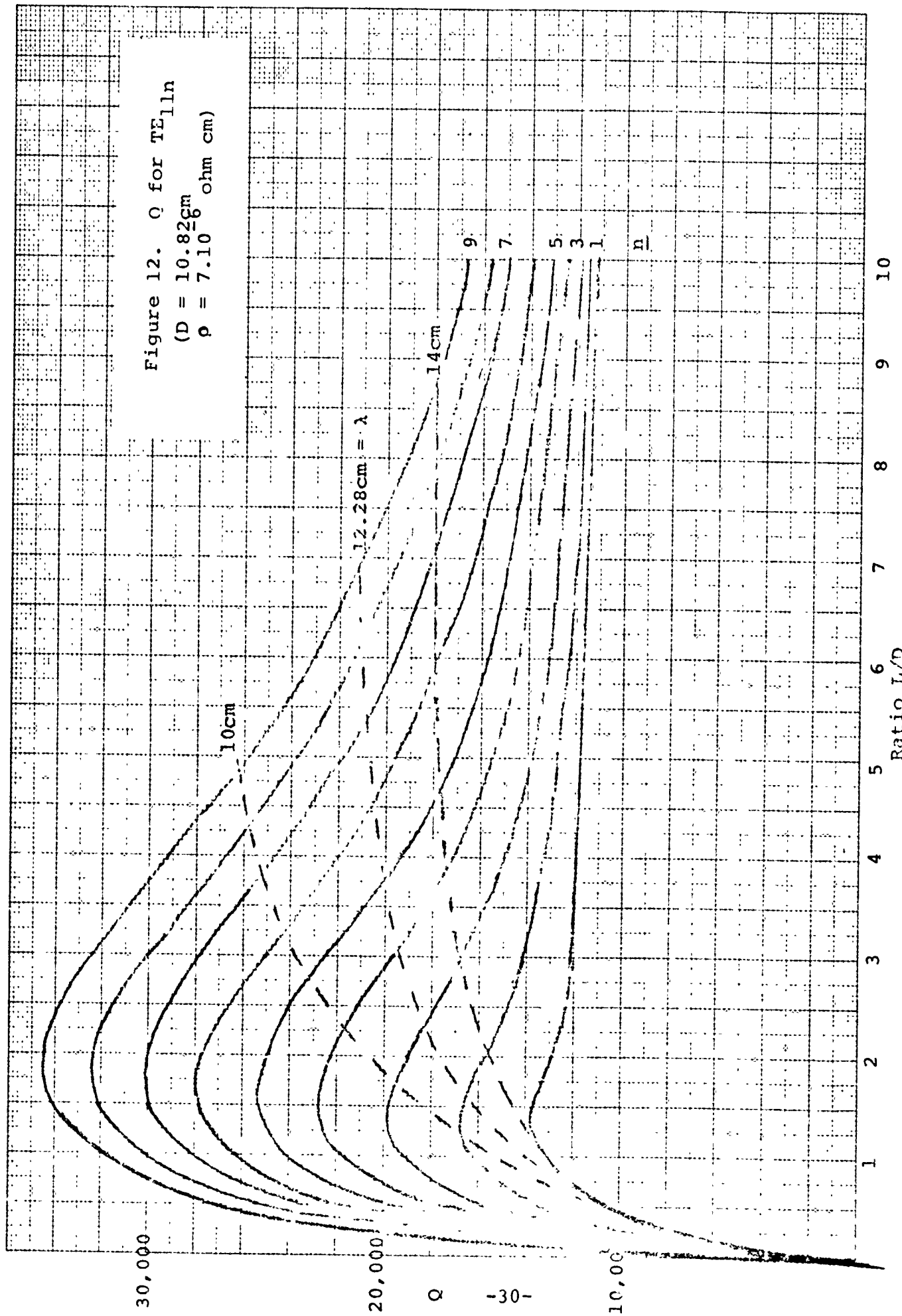
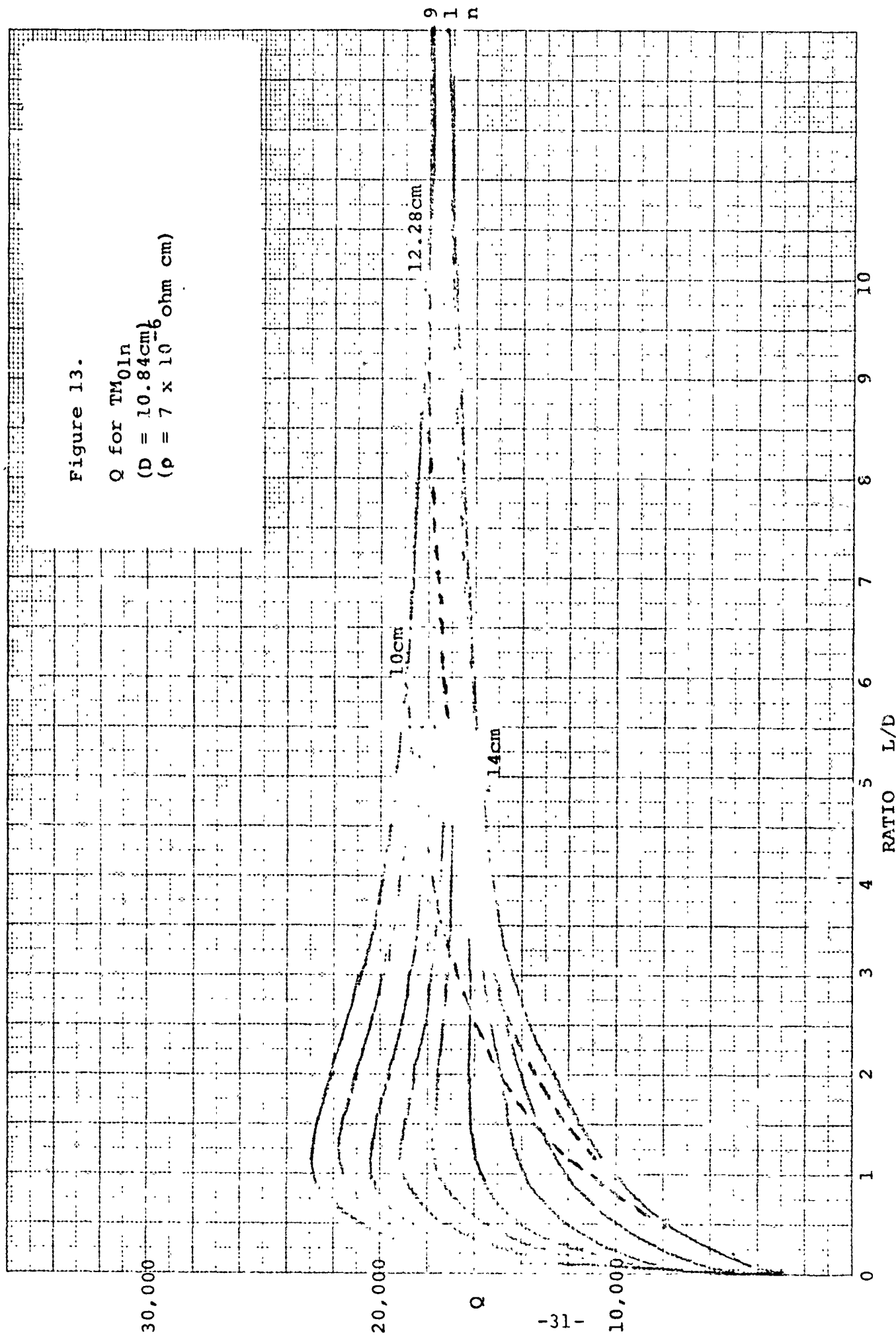


Figure 13.

Q for TM_{01n}
($D = 10.84\text{cm}$)
($\rho = 7 \times 10^{-6}\text{ ohm cm}$)



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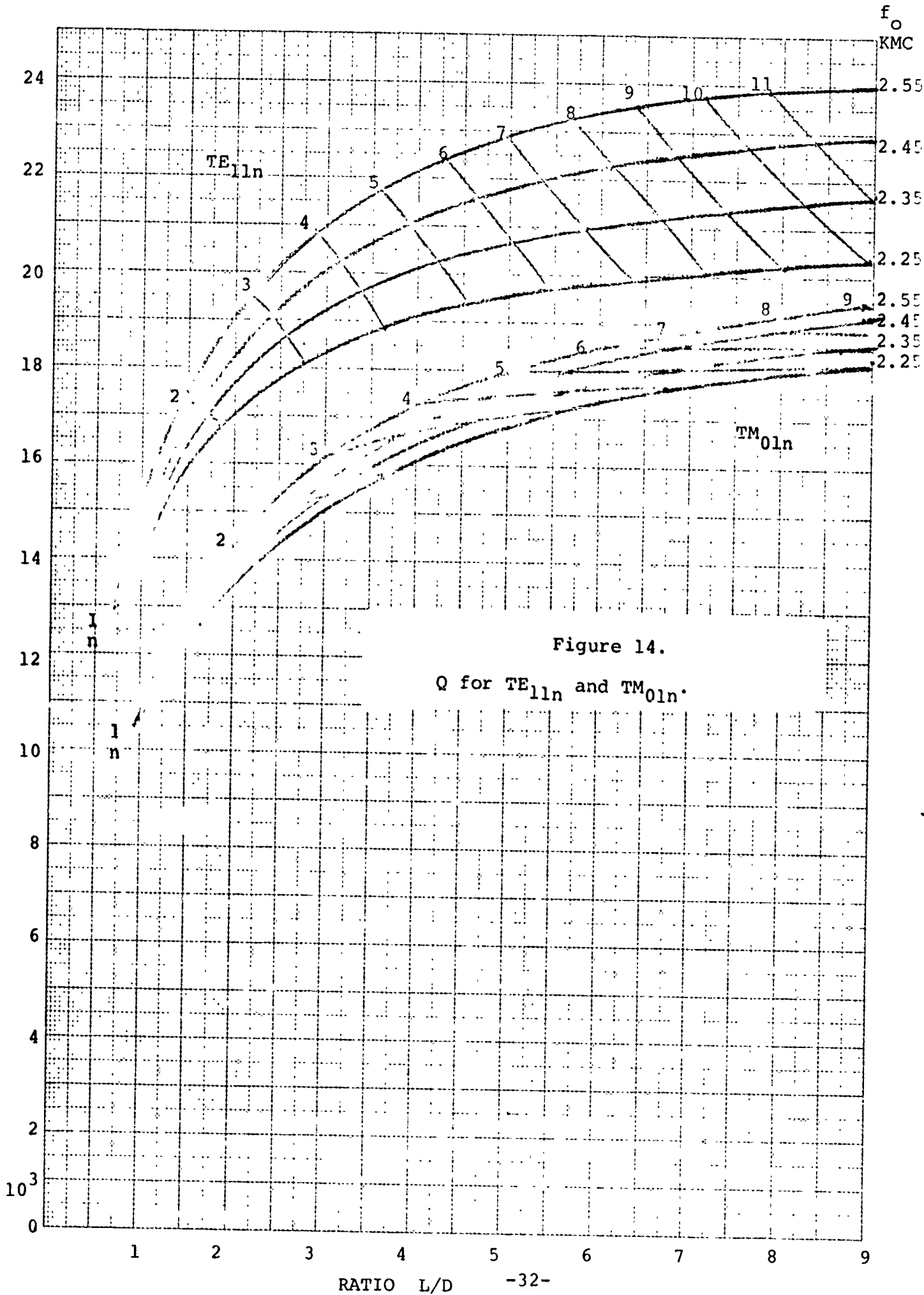


Table 11.5

	<u>Predicted</u>	<u>Measured</u>	<u>Measured (after alterations)</u>
TM ₀₁₆	18,500	18,460	not measured
TE ₁₁₉	22,500	12,370	8,010

The source of the losses in the cavity, as measured earlier, is most probably in the irregular surface offered by the threaded section required for the tuning piston. This could be reduced considerably by the extension of the piston in the form of a cup. Such a cup is merely a tubular extension of the edge of the piston in the cavity so that the irregular surface due to the threads are eliminated from the cavity. The alternative is to reduce the length of the existing cavity by attaching an extension to the tuning pistons that presents a new piston surface which remains beyond the threaded section. The cavity was altered by placing apertures on one end for introducing the microwaves. The additional structure at this end is probably contributing to the additional reduction in the Q. The apertures used for the coaxial probes will also contribute to the reduction in Q.

12.0 FIELD INTENSITY DISTRIBUTION IN THE SYMMETRICAL TM_{01n} MODE

The three equations:

12.1 $E_z = 0.8195 J_0 (0.4208r) \cos (0.2942z) E_0$, the axial field intensity at the axial point z

12.2 $E_r = 0.2411 J_1 (0.4208r) \sin (0.2942z) E_0$, the radial field intensity at the radial point r and axial point z

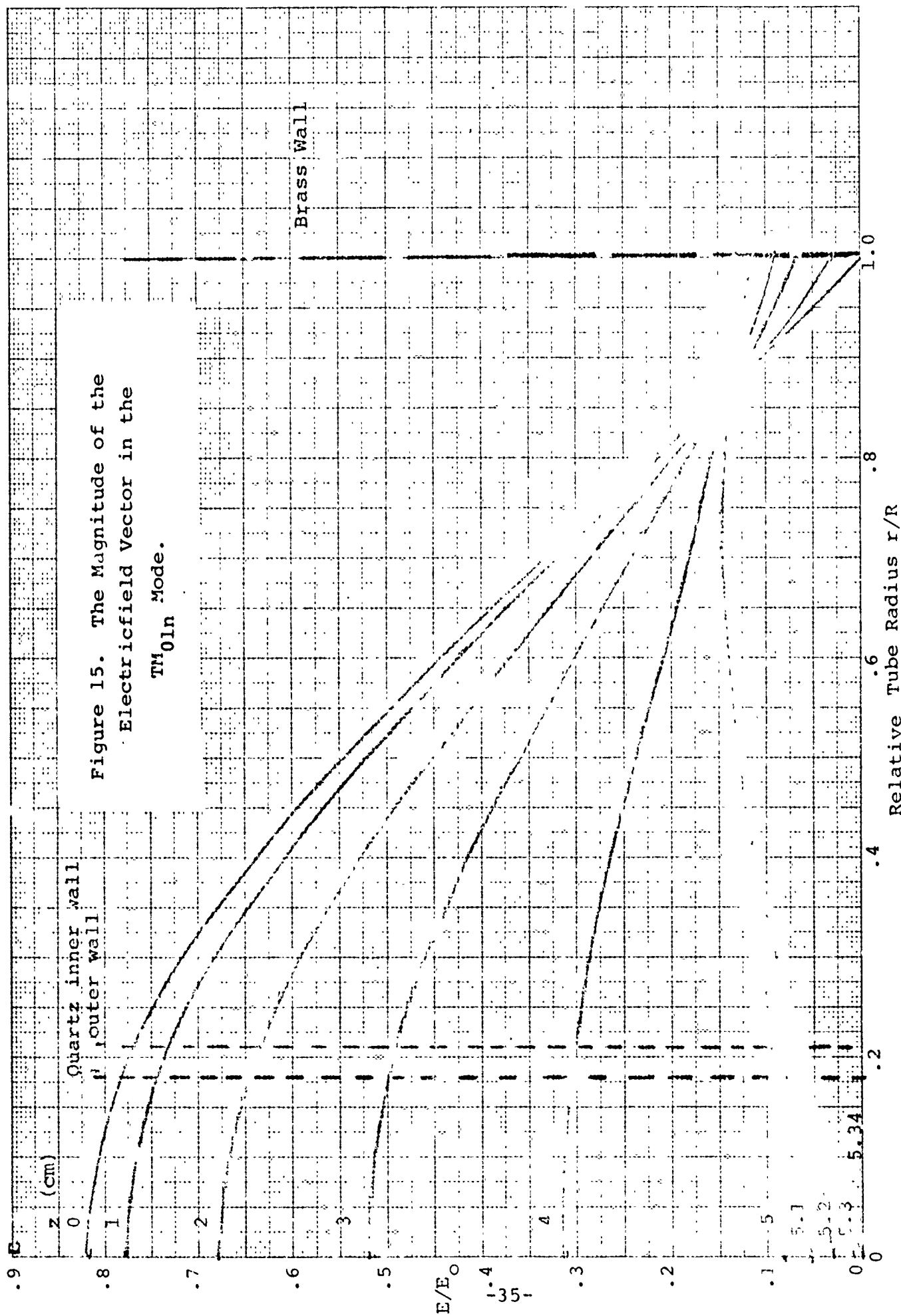
12.3 $E = (E_z^2 + E_r^2)^{1/2}$ the magnitude of the full field intensity are

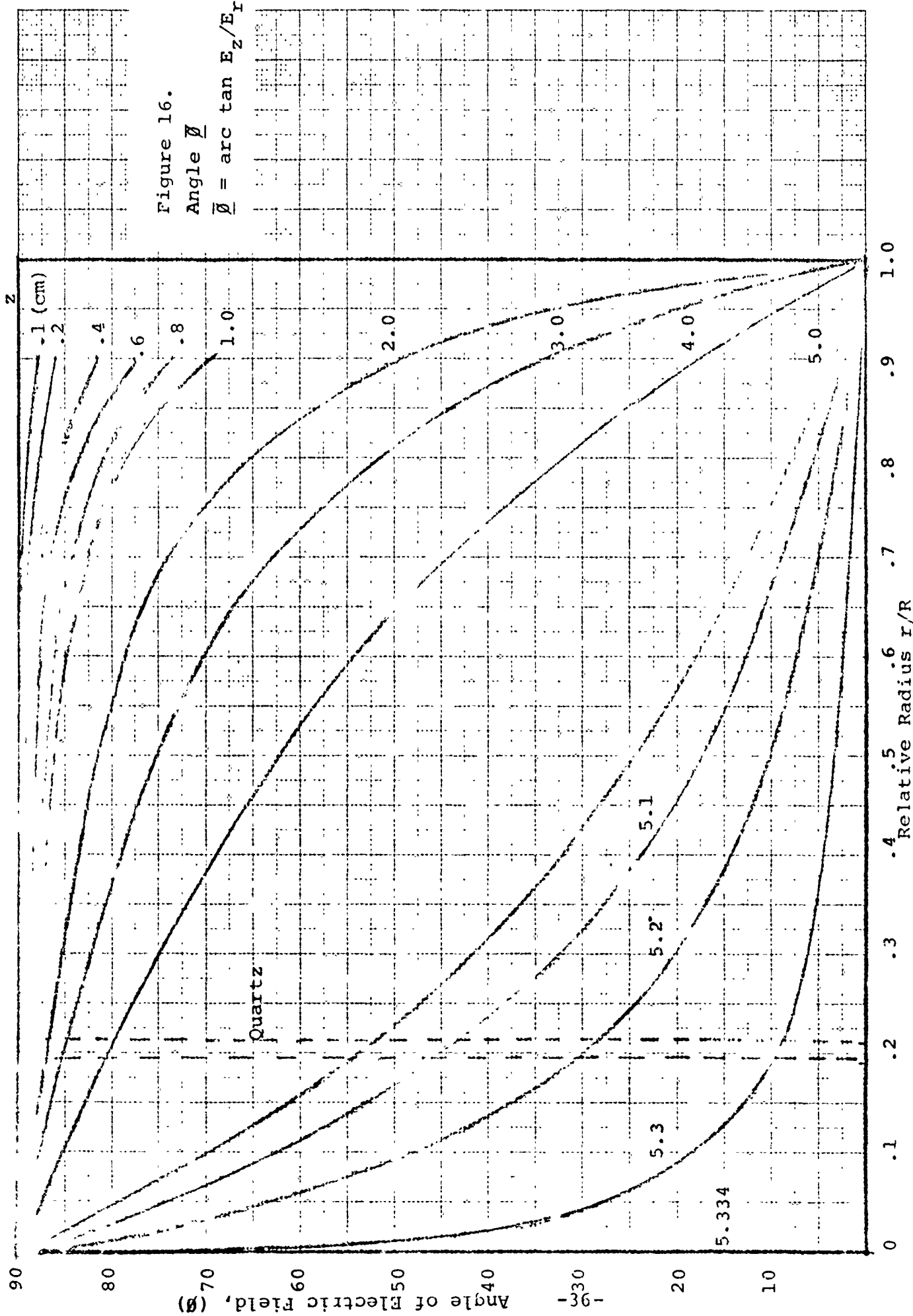
valid for 2.45×10^9 Hz. The tube dimensions were 5.715cm in radius in the TM_{01n} mode with $n/L = 0.0936$.

For the mode values n , the tube lengths L are,

n	L
6 half periods	64.07cm, 25.22 inches
7 half periods	74.75cm, 29.42 inches

corresponding to this basic configuration. The values of J_0 and J_1 are the usual Bessel functions and the field intensities E are normalized to the applied field E_0 . In this case E_0 must be considered the actual field generated by the magnetron at the entrance to the cavity multiplied by the Q of the cavity. Figure 15 shows the distribution of the field intensity as a function of the fraction of the tube radius at 1cm intervals along the z axis from the point of peak axial intensity. In the same cavity regions the direction of the electric vector has also been determined. Figure 16 presents this information graphically as a function of the fractions of the cavity radius with the z axis distances (in cm) as a parameter. The angle θ is 90 degrees when the electric vector lies parallel to the axis of the cavity, $E_r = 0$. Decreasing the diameter of the cavity increases the guide wavelength so that the distribution shown extends to more and more of the total length of the cavity. It may be shown for this frequency that a reduction in the radius to $R = 1.845$ inches, 4.68cm, from the present value should result in the distribution shown stretched out by a factor of 14.7 to 1 so that the present 5.334cm quarter wave point would occur at 78.46cm. Experimental verification can be performed by inserting a suitable copper sleeve and placing a smaller diameter extension on the tuning piston. The solutions





and placing a smaller diameter extension on the tuning piston. The solutions for the TE_{11n} mode may be obtained in the same manner. Our notation corresponds to that found in Ref. 6 P.299. At the lower pressures the plasma tube a relatively small value of Q will result in breakdown in this cavity at these field intensities. See Section 16 for the case of the travelling wave.

13.0 FREQUENCIES OF THE PLASMA

The basic resonances encountered in a plasma will include the following:

The Electronic Plasma Frequency

$$13.1 \quad \nu_{pe} = \frac{\omega_{pe}}{2\pi} = \left(\frac{n_e e^2}{\pi m_e} \right)^{1/2} = 8.97 \times 10^3 n_e^{1/2} \text{ Hz}$$

e = electronic charge (esu)

m_e = electronic mass (gms)

m_i = ionic mass (gms)

The Ionics Plasma Frequency

$$13.2 \quad \nu_{pi} = \left(\frac{n_i e^2}{\pi m_i} \right)^{1/2} \text{ hertz} = 2.09 \times 10^2 (n_i)^{1/2} \text{ Hz}$$

n_i = ions/cm³

The Collision Frequency

The collision frequency is a function of the diffusion coefficient and can be estimated from the time required to deflect a particle through a 90° in a kinetic collision. The methods of analysis are developed in Ref. 4 with the results that

$$13.3 \quad v_{\text{coll}} = \frac{17.94 n_0 e^4 z^4 \ln \Delta}{m_e^{1/2} (3kT)^{3/2}} = \frac{.9877 n_0 z^4 \ln \Delta}{M_e^{1/2} T^{3/2}} \quad \begin{array}{l} z = 1 \text{ for electrons} \\ M_e = 1/1823 \text{ in} \\ \text{atomic mass units} \end{array}$$

where the shielding coefficient is:

$$13.4 \quad \Delta = \frac{3}{2z_i e^3} \left(\frac{(kT)^3}{\pi n_e} \right)^{1/2}, \quad \begin{array}{l} z \text{ is the number of charges carried} \\ \text{by the particle, } n_0 \text{ is the total} \\ \text{number of particles per cm}^3 \text{ in the} \\ \text{cavity and } k \text{ is the Boltzmann constant.} \end{array}$$

Cyclotron Frequency

When there is a magnetic field present a frequency occurs which is a function of the strength of that field and the charge to mass ratio of the particles, thus:

$$13.5 \quad v_c = \frac{\omega_c}{2\pi} = \frac{ZeB}{2\pi mc} \text{ Hz for electrons, this reduces to}$$

$$13.6 \quad v_{ce} = 2.829 \times 10^6 B \text{ Hz.}$$

for ions, this reduces to

$$13.7 \quad v_{ci} = 1.54 \times 10^3 \frac{ZB}{M} \text{ Hz.}$$

Acoustic Frequencies

In addition, there will be chamber acoustic frequencies which will be a function of the chamber length L and the quartz plasma chamber diameter d for a simple tubular chambers. To illustrate the frequency

$$13.8 \quad v_{aL} = \frac{v_{\text{acoustic}}}{2L} = \left(\frac{Z\gamma_e kT_e + \gamma_i kT_i}{4m_i L^2} \right)^{1/2} \text{ Hz would correspond to the longitudinal modes only.}$$

Clearly the plasma frequency and collision frequency can be of the same order as the driving frequency by a judicious choice of temperature, pressure, and species. Attaining 10^{11} electrons/cm³

electron density could give an S band plasma frequency while about 1.4×10^{19} particles per cm^3 at room temperature results in a S band collision frequency. To attain a cyclotron frequency of this order, a field of about 1000 gauss is required.

Other potential acoustic frequencies for the radial modes could come into play most prominently in conjunction with the pulse repetition frequency associated with a pulsed microwave source. A hydrodynamic cylindrical shock wave generator could be the result with all the peculiarities associated therewith. Ref. 5. Detailed specifications for some of the frequencies are included in a developing literature which includes references 10 to 16 for the simple cylindrically symmetrical cavities.

14.0 REFRACTIVE INDEX OF THIN PLASMAS

The propagation of electromagnetic waves in a plasma is characterized by the dielectric constant of the medium. In the absence of both a significant attenuation and an applied magnetic field, the plasma exhibits a real index of refraction μ . This refractive index is a function of a ratio of the plasma frequency ω_p to the frequency ω of the incident electromagnetic wave. As long as the ratio is less than 1 this refractive index is real and less than 1. The refractive index is not a function of the angle of incidence on the plasma under these circumstances, there is an angle of incidence that is equivalent to the Brewster's angle in optics. At this angle there is a minimum surface reflectivity. The Brewster angle for this condition is

$$14.1 \quad \theta_B = \tan^{-1} \mu.$$

The result of an index of refraction, μ , less than 1 for the

plasma means that there is a critical angle, θ_{cr} , beyond which total reflection occurs. This is encountered when the electromagnetic wave proceeds, through the interface between freespace and the plasma, from freespace side of the interface. This angle has the value

$$14.2 \quad \theta_{cr} = \sin^{-1} 1/\mu.$$

If the value of the frequency ratio ω_p/ω exceeds unity the refractive index becomes imaginary and it is not possible to use a simple linearly polarized wave and obtain a minimum reflection since $\tan \theta_B$ is imaginary.

The value for the frequency ratio that results in this refractive index μ

14.3 $\mu = (1 - (\omega_p/\omega)^2)^{1/2}$ is obtained from the plasma frequency which is a function of the electronic charge, mass and density of charge. In a plasma composed of positive charges of mass, m_i , and n_e , negative charges of mass m_e one obtains a plasma frequency ratio

$$14.4 \quad \frac{(\omega_p^2 + \omega_p^2)}{\omega^2} = \left[\frac{n_e e^2}{\epsilon_0 m_e} + \frac{Z n_i e^2}{\epsilon_0 m_i} \right] / \omega^2 = \left(\frac{\omega_p}{\omega} \right)^2$$

The condition of electrical neutrality requires $Z n_i = n_e$ therefore:

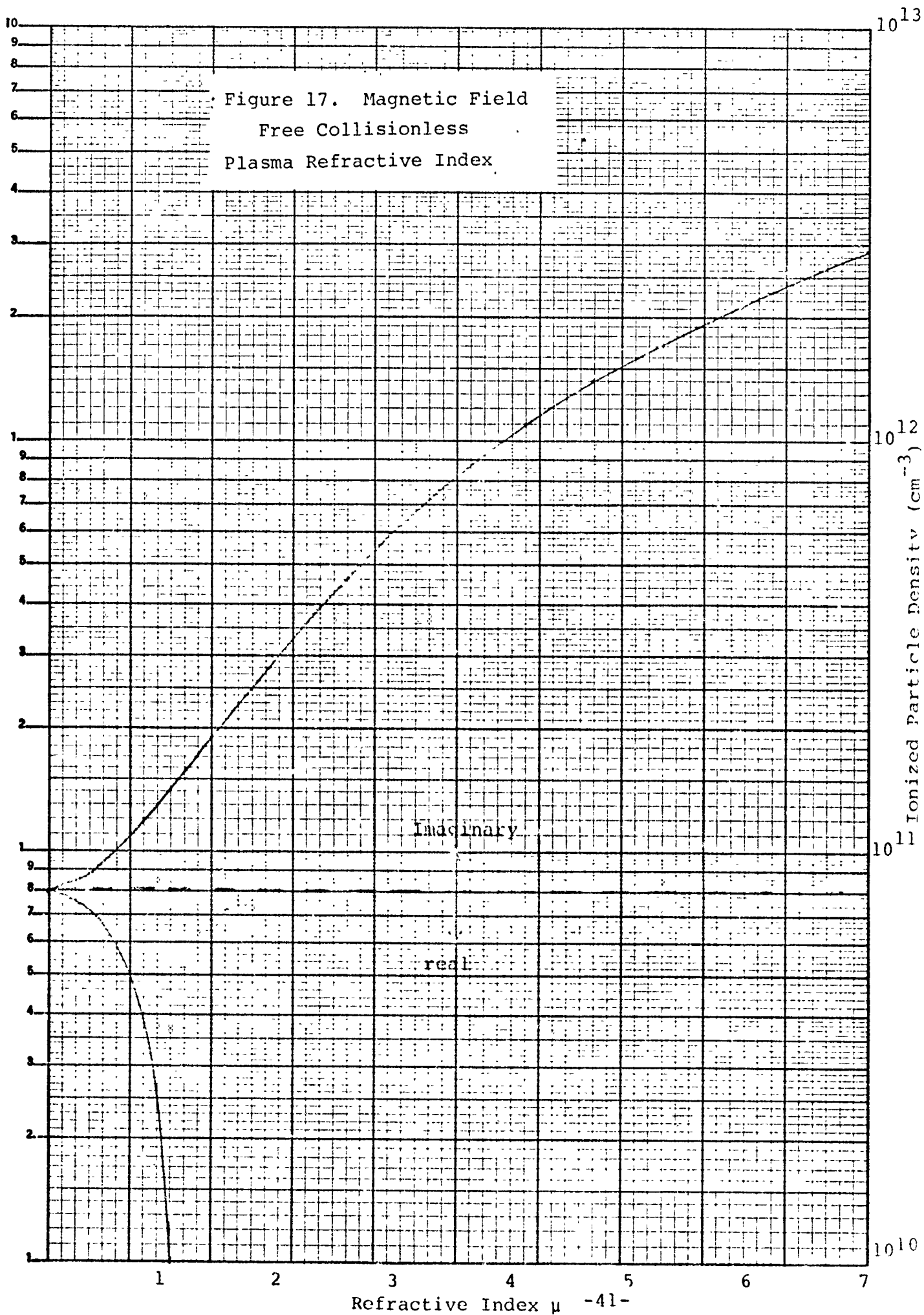
$$14.5 \quad (\omega_p/\omega)^2 = \frac{n_e e^2}{\epsilon_0 m_e \omega^2} \left[\frac{M + 1}{M} \right] \quad \text{where } M = \frac{m_i}{m_e}$$

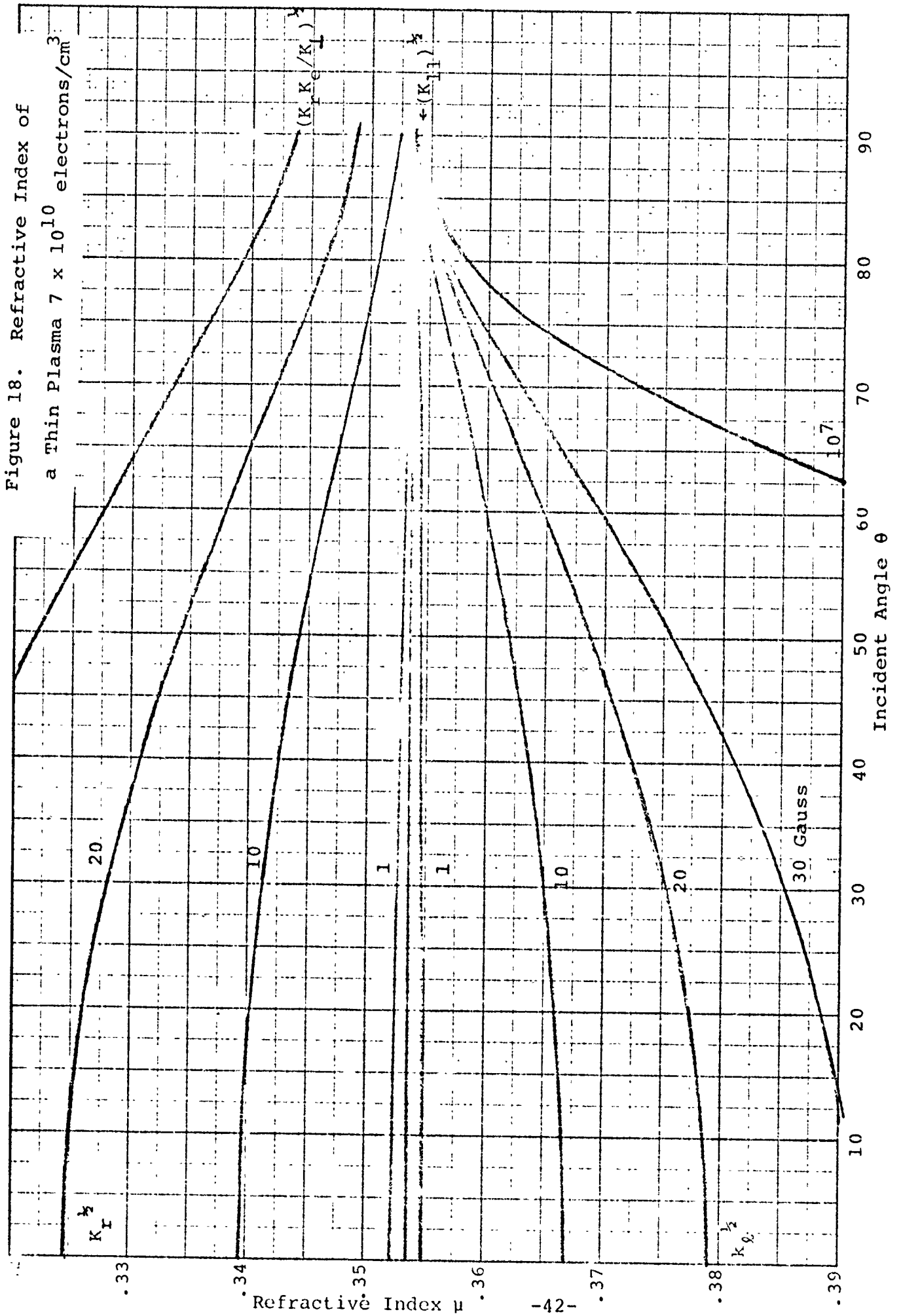
and ϵ_0 is the permitting of free space.

The functional relation between the electron density and the refractive index for this simple plasma is:

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Figure 17. Magnetic Field
 Free Collisionless
 Plasma Refractive Index





$$14.7 \quad \mu = \left[1 - \frac{n_e e^2}{\epsilon_0 m \omega^2} \left(\frac{M+1}{M} \right) \right]^{\frac{1}{2}}$$

When S Band microwaves, 2.54×10^9 hertz, are used, figure 17 becomes the graphic representation for this equation. It shows both the real and the imaginary values for the appropriate electron densities. The application of a DC magnetic field may be shown to modify the refractive index radically (Ref. 23). See Section 15. The application of these appropriate equations result in extensive modifications of the plasma characteristics for the various forms of polarized incident waves. Some refractive indices are shown in figure 18 for a selected electron density and for several selected intensities of a constant applied magnetic field.

There are four limiting indices two of which occur at normal incidence and two of which occur at grazing incidence these are:

$$14.7 \quad \mu_r = k_r^{\frac{1}{2}} \text{ for right circular polarized waves}$$

$$\mu_l = k_l^{\frac{1}{2}} \text{ for left circular polarized waves}$$

at the incidence of angle $\theta = 0$ degrees

$$14.8 \quad \mu_{||} = (k_{||})^{\frac{1}{2}} \text{ linear parallel polarization}$$

$$\mu_{\perp} = \frac{k_r k_l^{\frac{1}{2}}}{k_l} \text{ linear perpendicular polarization.}$$

At an incidence angle of $\theta = 90$ degrees. The effect of the various magnetic fields is shown parametrically.

If transport theory is introduced, Ref. 23 Chapter 5, the plasma becomes alive with additional potential effects which are a

function of the electron energy. Representative cases for a 2000 Gauss DC field are shown in figure 19 to 22 where each group is for a specific electron density.

15.0 REFLECTIVITY OF A THIN PLASMA

The concept of a skin depth in the "thin plasma" refers to the wavelength created in the plasma by the frequency of a driving microwave source. For this region the free space wavelength of the microwave source is less than the wavelength in the plasma. The implication is that a less dense "dielectric" material is being entered from a more dense medium and Fresnel relations from an index of refraction are valid. This comes from the following basic concepts.

If one investigates the solution of Maxwell's equations for a plane wave (Ref. 31, P.271, etseq) there is obtained a simple solution for the field intensity perpendicular to the direction of propagation of the form

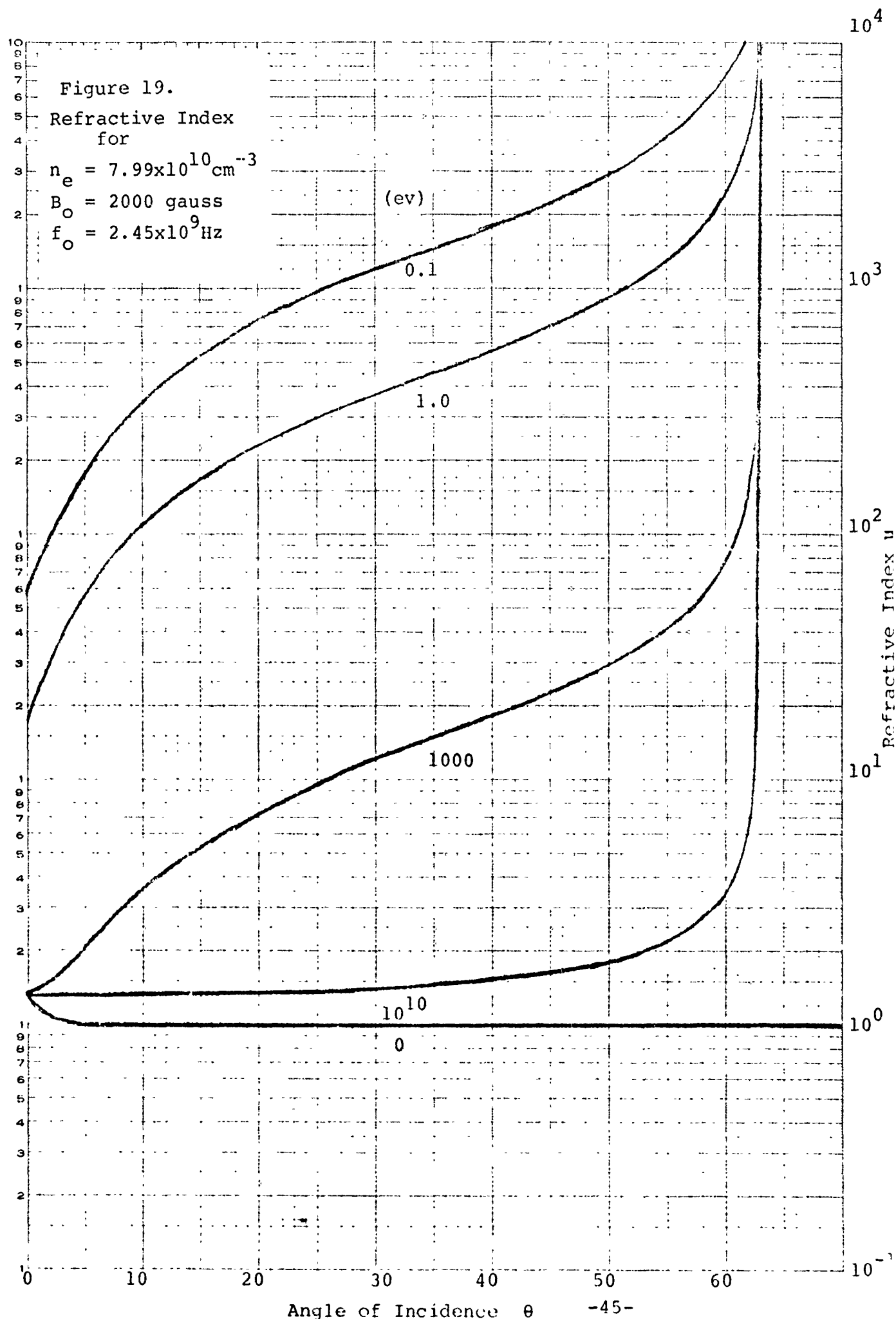
$$15.1 \quad E_{\xi} = E_{0\xi} \cos (\omega t - \alpha \zeta - \theta,)$$

if the plane wave is going in one direction only and the conductivity of the medium is zero. This field is periodic in both space and time and $\omega = 2\pi f$ where f is the frequency. The period along the time axis is $2\pi/\omega = T$. The period along the space axis is the wavelength which is $2\pi/\alpha$ where α is the real part of the propagation constant $k = \alpha + i\beta$, $\beta = \beta(\rho) = 0$.

The argument $\phi, = \omega t - \alpha \zeta - \theta$, of this periodic function is defined as the phase and θ , is the phase angle. If the plane $\zeta = \text{constant}$ at time $t = 0$ the question is how must it be displaced along the ζ axis in order that it remain invariant for a change in t . Since

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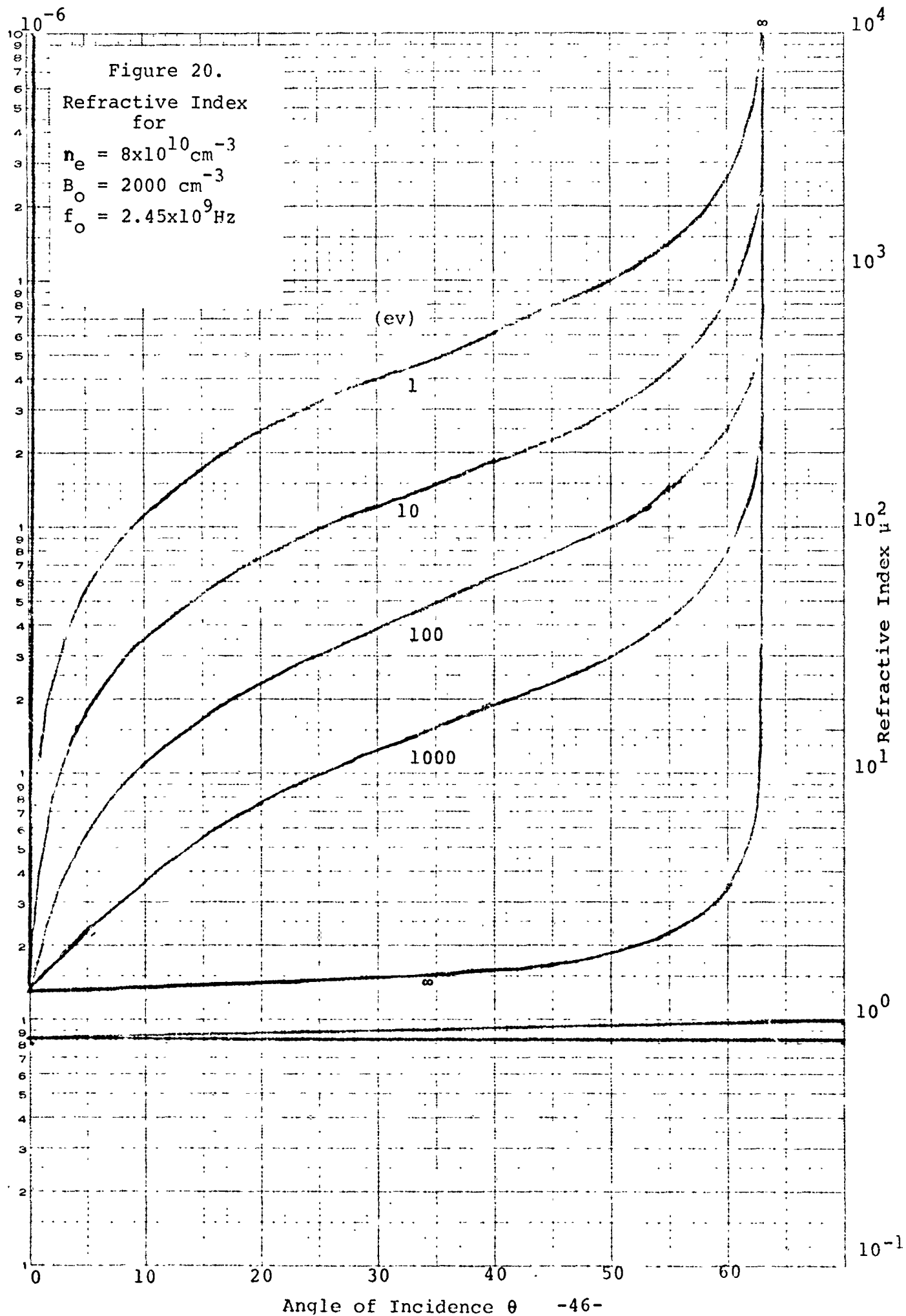
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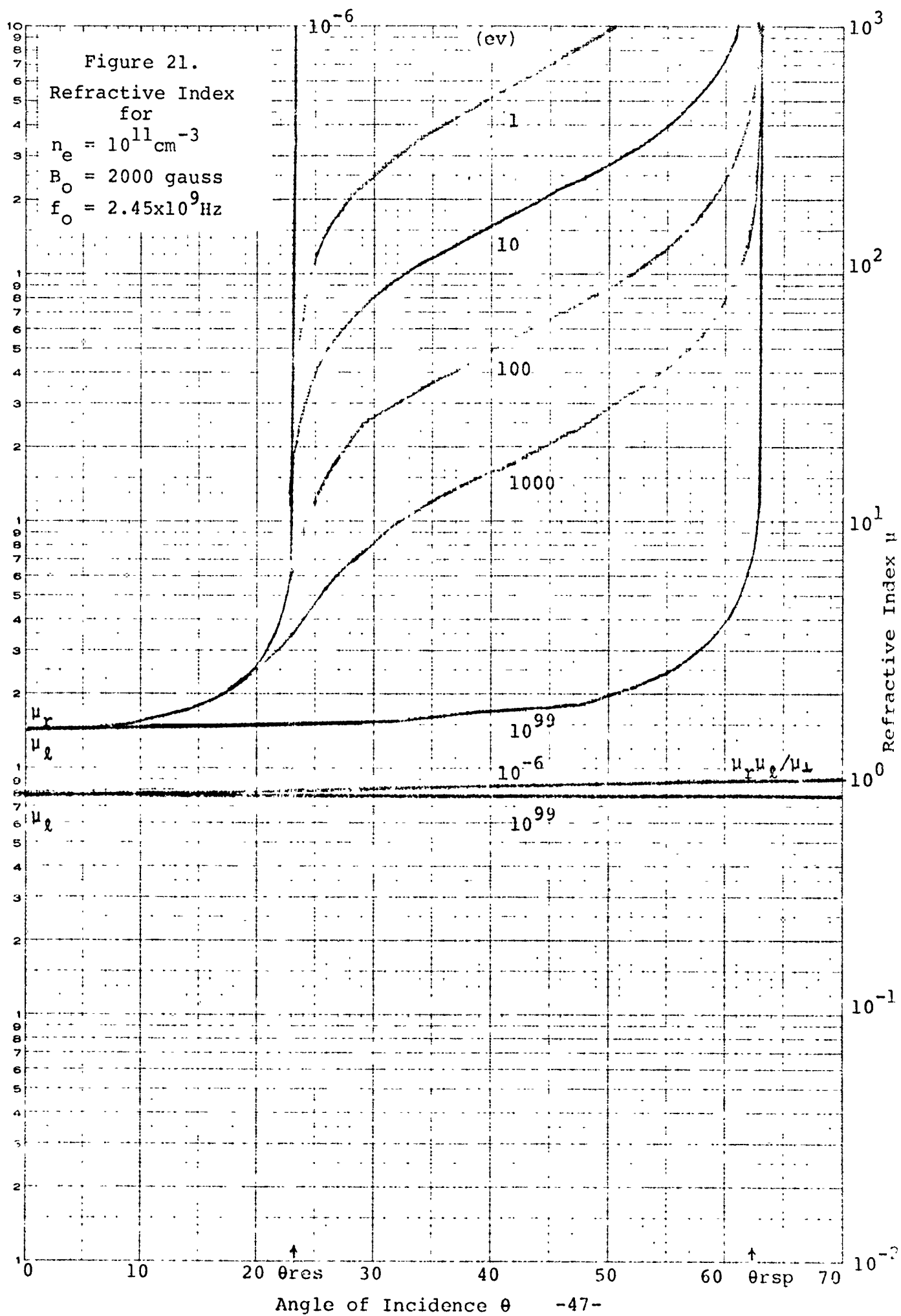
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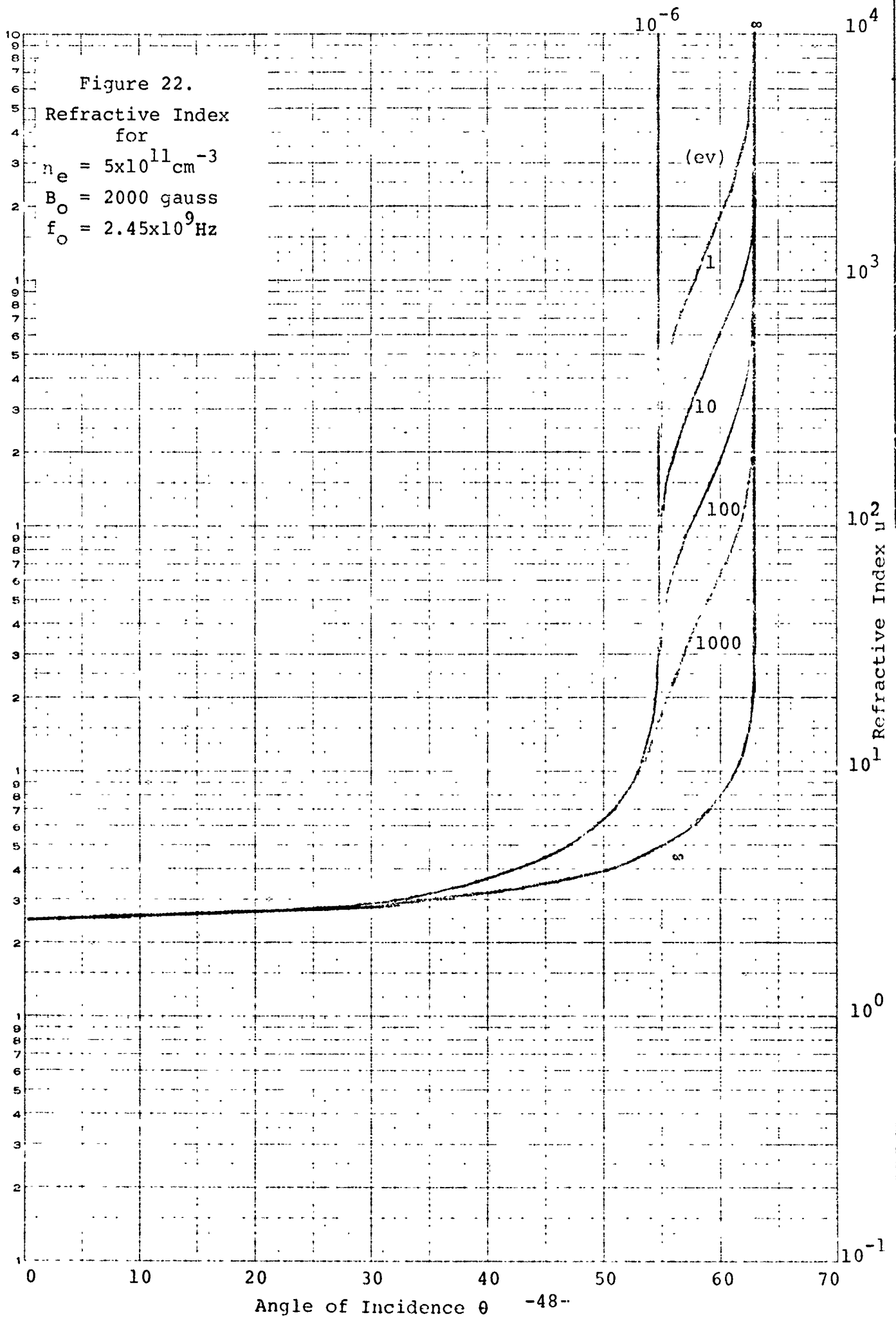


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15.2 $\phi_1 = \omega t - \alpha \xi - \theta$, constant then the derivation

15.3 $d\phi_1 = \omega dt - \alpha d\xi = 0$ and the velocity along the axis

$$V = d\xi/dt = \omega/\alpha$$

but for a nonconducting medium it is found that

$$15.4 \quad \alpha = (\mu, \epsilon)^{1/2} \omega$$

The phase velocity is then simply equal to

$$15.5 \quad V = \frac{1}{(\mu, \epsilon)^{1/2}}$$

If the velocity in free space is

$$15.6 \quad C = \frac{1}{(\mu_0 \epsilon_0)^{1/2}}$$

the refractive index is

$$15.7 \quad \mu = \frac{C}{V} = \frac{(\mu, \epsilon)^{1/2}}{\mu_0 \epsilon_0^{1/2}}$$

A cylinder of "thin" plasma may be considered as a waveguide section.

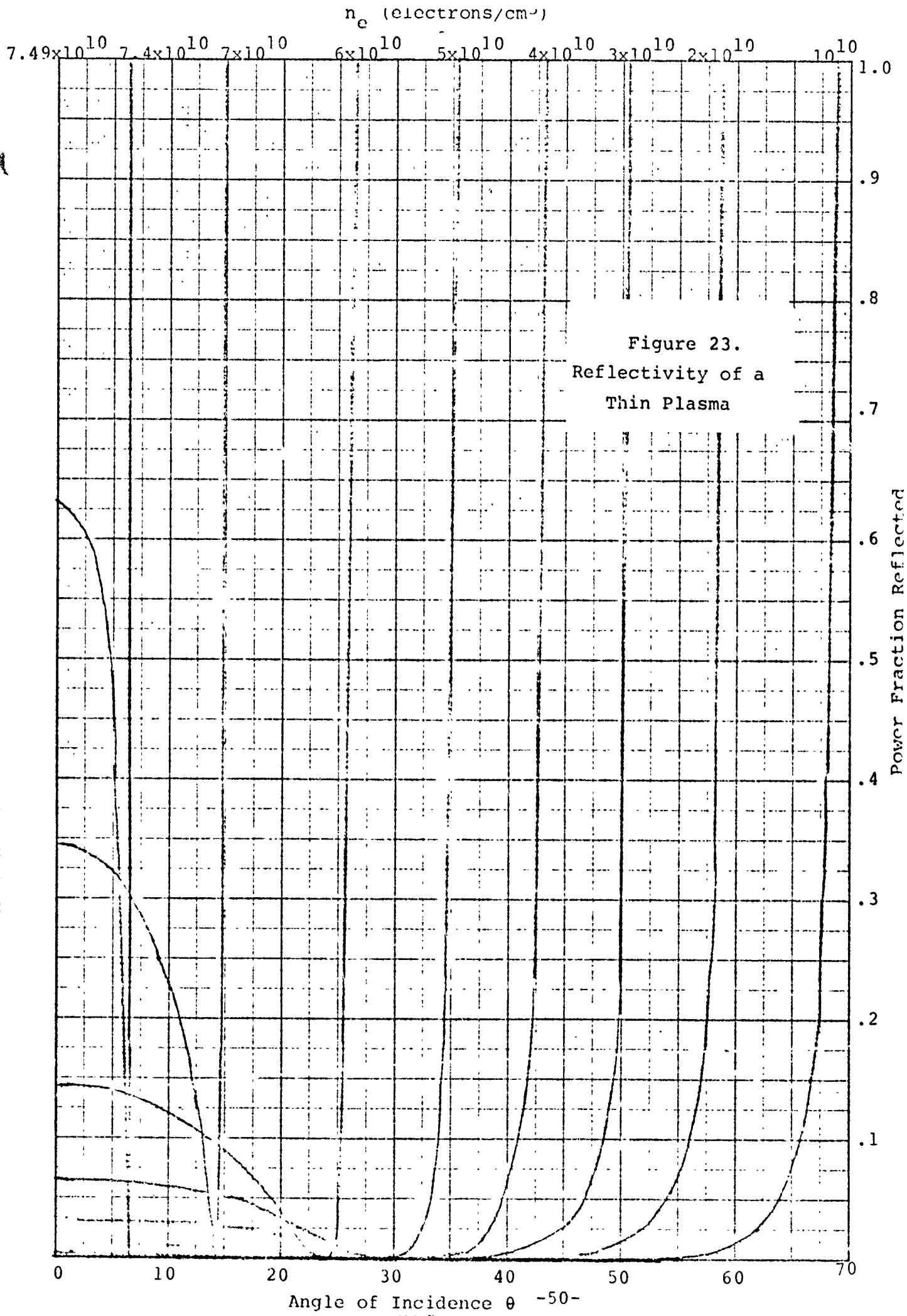
The normal incidence of an electromagnetic wave on such a thin plasma will therefore result in a reflection at the interface, which is a function of the refractive index, μ . This latter may be written in terms of a function of the ratio of the wavelength inside the plasma λ_p wavelength in free space λ_0 that is incident on the plasma i.e.:

$$15.8 \quad \mu^2 - 1 = \left(\frac{\lambda_0}{\lambda_p} \right)^2 \left(1 + \left(\frac{Z}{M} \frac{n_i}{n_e} \frac{m_e}{m_i} \right) \right)$$

To this approximation, the refractive index is

$$15.9 \quad \mu = \left[1 - \left(\frac{\lambda_0}{\lambda_{pe}} \right)^2 + \left(\frac{\lambda_0}{\lambda_{pi}} \right)^2 \right]^{1/2}$$

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where λ_{pe} is the wavelength in the plasma if the plasma were composed of electrons alone and λ_{pi} is the wavelength in the plasma if the plasma were composed of ions alone.

In such a plasma the unique angle that results in smallest amplitude reflected wave is Brewster's angle. This angle is obtained for that linearly polarized EM wave that has its E component lying in the plane of incidence at the boundary between the two media. At Brewster's angle the sum of the angle of incidence θ and the angle of refraction r , is 90° , therefore $\tan \theta = \mu$ from Snell's law.

To illustrate consider a case of "thin" plasma with no magnetic field and a negligible collision frequency. When a 12.2 cm S band microwave is incident thereon, the value of the refractive index, μ is $\mu = (1 - 1.33 \times 10^{-11} n_e)^{1/2}$. The reflectivity R , at normal incidence, is $R = \left(\frac{\mu-1}{\mu+1} \right)^2$.

In the absence of significant absorption, then, the reflectivity may be specified as a function of the electron density, figure 23. The curves are shown as a function of the angle of incidence on the plasma. Each of the curves corresponds to a single value of electron density when a microwave having a freespace wavelength of 12.2 cm is impinging. The interpretation, up to, $n_e = 7.49 \times 10^{10}$ electron/cm³ for S band is that there is, always an angle of incidence for the parallel polarization of the EM wave at which no reflection occurs.

Because the phase velocity is greater than the velocity of light in the medium confining the plasma it is not possible to confine this applied EM wave within this form of plasma. If, however, the collision frequency remains negligible it is possible by applying

a dc magnetic field to make the phase velocity less than the velocity of light. The refractive indices are still real and have the values.

$$15.10 \quad \mu = \left[1 - 8.96 \times 10^{-14} n_e \lambda^2 (1 \pm \lambda/\lambda_{co})^{-1} \right]^{1/2}$$

$$15.11 \quad \mu = \left[1 - 8.96 \times 10^{-14} n_e \lambda^2 (1 \pm 5.136 \times 10^{-8} \frac{m_i}{M} Z B \lambda)^{-1} \right]^{1/2}.$$

Therefore, for a singly ionized plasma $Z = 1$ with the electron population n_e , $M = m_e$, the S band wavelength, $\lambda = 12.2$ the index of refraction reduces to

$$15.12 \quad \mu = (1 - 1.33 \times 10^{-11} n_e (1 \pm 1.15 \times 10^{-3} B \text{ (Gauss)}^{-1})^{1/2}.$$

There is, therefore, always a real refractive index of one of the incident circularly polarized wave when the negative sign is chosen and the magnetic field exceed the value $B > 1.95 \times 10^7$

$$\frac{M}{m_i Z \lambda} \text{ Gauss.}$$

Again for electrons, $B > 1.05 \times 10^4 / \lambda$ Gauss. Where λ is in cm. You will note that when 5×10^5 Hz is involved λ is of the order of 6×10^4 cm and $B > 0.18$ Gauss would be representative. As an example the earth's magnetic field is at least 0.25 Gauss at the ionized layers of the atmosphere, the index of refraction is greater than 1 regardless of the electron density only provided that the collision frequency is \ll than 5×10^5 Hz. This condition is met in the D, E, F regions of the ionosphere and was one of the first tests of the theory.

The clear implication is that a circularly polarized microwave can be guided in a plasma with a static magnetic field. This index can be varied by changing the field intensity thereby permitting the use of a single frequency. The electron density and electron velocities are then controlled by the pressure of the

plasma. This establishes the fact that controls are now available for tailoring the excitation mechanisms for particular population inversions.

16.0 CALCULATION OF THE PEAK FIELD INTENSITY AS A FUNCTION OF THE POWER INPUT FOR A TRAVELLING WAVE

The peak field intensity of a travelling wave in a circular waveguide has been computed for a specific power flow. (See Moreno, Microwave transmission data, Dover 1948, P.124,125) the cases are:

For TE_{11} mode

$$16.1 \quad E = \left(\frac{503}{a^2} \left(\frac{\lambda_g}{\lambda} \right) P \right)^{\frac{1}{2}} \text{ volts/cm.}$$

for the existing geometry $a = 5.715 \text{ cm}$

$\lambda = 12.24 \text{ cm}$

$\lambda_c = 19.50 \text{ cm}$

$\lambda_g = 15.71 \text{ cm}$

$P = \text{Power (watts)}$

$$16.2 \quad E = 4.447 P^{\frac{1}{2}} \text{ volts/cm}$$

This occurs on axis.

The case of the TM_{01} involves two situations. The first results when $a/\lambda < 0.761$. In this case the maximum field intensity occurs on axis. The equation

$$16.3 \quad E = \left(130 \frac{\lambda^2}{a^4} \left(\frac{\lambda_g}{\lambda} \right) P \right)^{\frac{1}{2}} \text{ volts/cm.}$$

For this mode the geometry changes the values of $\lambda_c = 14.93 \text{ cm}$ and $\lambda_g = 21/35 \text{ cm}$.

$$16.4 \quad E = 5.64 P^{\frac{1}{2}} \text{ volts/cm.}$$

at $P = 1 \text{ kw}$ $E_{TE} = 145 \text{ V/cm}$ and $E_{TM} = 178 \text{ V/cm}$.

serious lack of data for the remaining II-VII compounds. It is suggested that an investigation of this paucity of data and some more extended thermo chemical calculations are in order. Section 5 lists some of the preliminary data that will be required to extend this type of study.

2b. The electron temperature estimation in Section 6 based on the Von Engle - Steenbeck method has been applied to those noble gases for which a legitimate value the constant C could be postulated. Similiar estimates should be made for other of the vapors and gases that could offer a buffer potential. The H_2O vapor that has been so effective in the $BaCl_2$ experiments in particular should be evaluated in more detail.

2c. Section 7 developes the radial density distribution encountered in a wall confined plasma. Such a distribution will be much less liable to exhibit a strong reflection when the steep portion of the gradient is of the order of a $\frac{1}{4}$ wavelength than when the gradient is sharp enough to be considered to be a discontinuity. Advantage should be taken of this characteristic. The relation to the skin depth which is treated in section 10 should be amplified.

2d. The field intensity distribution in the TM_{01n} mode has been shown in Section 12. The unique character of the magnitude of the field intensity at $r/R_0 = .87$ staying virtually constant at about .18 of E_0 may be useful. At this distance only the direction of the vector field is changing. The TE_{11n} mode should also be investigated.

2e. The most interesting aspect of sections 14 and 15 is the truly tremendous range of potential values for the refractive index when the magnetic field is introduced and the extraordinary effects introduced by increasing the initial energy of the electrons. It will be the developement of this work that will lead to the ultimate in the final designs.

18.0 RECOMMENDATIONS

1. Future Cavity Modifications

It is recommended that future cavities be constructed with flanges at both ends. Sealing shall be both for vacuum and for microwave integrity. The use of a hard vacuum in the cavity around the quartz tube will eliminate the convective losses and insure that the cavity surface will remain oxide free. This could reduce the total cavity loss to a few watts while permitting the quartz tube wall to operate at more temperatures that are more than 1000°C . A thinner tube quartz wall would reduce the total emission by the quartz wall. The freedom from oxygen will allow an interior coating of silver in the cavity which will insure; a, the increase in Q; b, the reduction in effective emissivity; and c, the reduction in the loss of visible and ultra violet radiant power from the plasma itself. The end plates of the cavity should contain the screw thread for the tuning pistons. These should be on both sides of the cavity. The controls for both the fill and vacuum equipment of the laser tube and for the auxiliary vacuum envelope shall be on one of the end plates. The tuning pistons should be designed with a flange quarter wave choke. The losses introduced by a well made tuning piston of this sort will be less than 0.001 db per piston. The feed through for cavity excitation should be a coaxial line with micrometer tuning on each of the four input probes.

Since the differential pressure between the cavity and the laser tube is small a simple O ring seal may be considered between the quartz tube and the end plates of the cavity. This allows the

Brewster windows to be attached to the metallic extension of the plasma tube. Because of the unique character of the laser beam these windows and the closing laser mirrors may be situated at a considerable distance from the active region. The length of this "Buffer gas region" can reduce the potential for window contamination enough so that only the mildest of aerodynamic windows is required. It might be possible to use the pulse frequency of the magnetron to make the plasma itself act as a piston for operating the aerodynamic window.

The cavity volume is sufficiently large to allow the insertion of various structures with geometries that correspond to both cylindrical and spherical coordinates. Such loose structures as slow wave lines and consecutive cavities may also be examined.

A long solenoid should be wrapped around the cavity capable of producing axial magnetic intensities up to 10,000 oersteds for short periods and 1,000 oersteds on a d.c. basis.

2. Extensions in the Analytic Work

The analytic work, to this point, must be considered as preliminary because of the wealth of conditions that may be imposed on the plasma and the varied responses that can be expected. Much of the future analytic work will be dictated by the results of the experimental testing program. Some points, however, should be expanded upon among these are:

2a. Section 4 identifies the vapor pressure and densities obtained on the basis of present data this is somewhat lower than the values used by Frayne from the International Critical Tables. There is a

19.0 SUMMARY

This report presents the basic material that was used to develop the cavity design. A partial reference list is included concerning only those aspects that are fundamental to the problem.

From this, we have refined our understanding of the interface conditions between the plasma, the plasma envelope, and the waveguide. Factors such as the latter, however, must not dictate the cavity design because such high sensitivity would not permit stable operation. The design has been based on the ability to adapt to all reasonable modifications such an experimental system might encounter. To this end the structure is a large diameter cavity containing a number of longitudinal half wave periods. Both standing waves and travelling waves can be introduced. Linearly, lavio and dextro rotary circularly polarized waves can be introduced. The cavity size is sufficiently large to permit insertion of various potential configurations such as involve the increase in the, in-guide, wavelength, loosely coupled consecutive $\frac{1}{2}$ wave cavities, slow wave structures and conical cavities. The reflectivity of the interior of the microwave cavity is sufficiently high to reduce the radiative transfer between the microwave cavity wall and the plasma envelope. This permits the quartz envelope to operate at a high temperature even though the brass cavity is at less than 100°C . A reexamination of the available vapor pressure data on magnesium and the magnesium halides shows a need for additional experimental work in this field particularly at the lower temperatures. Reasonable electron temp-

eratures have been predicted for the noble gases as buffers. The radial electron density has been estimated as a function of the core electron density. The resistivity of the plasma has been obtained as a function of the electron density and temperature. The quartz tube diameter is equal to the skin depth at 1.3×10^{11} electrons/cm³ on the assumption of a constant electron density. The theoretical cavity Q was not obtained although the TM₀₁₆ mode was close. The alterations in the method of cavity excitation caused a decrease in the Q to 8000 in the worst case. The magnitude and direction of the field intensity were established in the resonant cavity modes. The peak field intensity was obtained for the travelling wave mode. The expected plasma frequencies were obtained and estimates of the effects of these frequencies and electron densities and energies on the refractive index of the plasma have been indicated. The effect of introducing a longitudinal magnetic field has also been indicated. The external character of the cavity has been maintained clear so that such longitudinal magnetic fields might be readily applied. The laser mirror mounting was constructed independently of the overall cavity and mounted on an invar rod. Temperature variations in the cavity will not affect the size to the laser cavity. An all quartz tube was designed to allow the Brewster windows to operate at a higher temperature than the Quartz envelope. This is to reduce the potential for condensation on the window surfaces. The microwaves are introduced either by the apertures at the end of the cavity or by the coaxial couplings in the cavity walls. Suitable isolation of the magnetron is obtained by good microwave practice.

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APPENDIX I
OPERATING INSTRUCTIONS AND TEST DATA

**S-Band Cylindrical Cavity
for Laser Excitation**

**Operating Instructions
and
Test Data**

November 13, 1980

ITT AVIONICS DIVISION
380 Washington Avenue, Nutley, N.J. 07110

CONTENTS

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II	GENERAL DESCRIPTION
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	B. Cavity
	C. Test Setup
III	OPERATION
	A. RF Source
	B. Cavity
	C. Test Setup and Tuning Procedure
IV	TEST DATA

I. INTRODUCTION

The equipment described herein was developed by ITT Avionics for the U.S. Army, Ft. Belvoir, Va. under Contract No. DAAK 70-79-C-0171. It consists of a high power S-band source, which is coupled to a cylindrical cavity in which the microwave energy is used to excite a plasma for laser experimentation. This report contains a brief description of the equipment (Section II), Operating Instructions (Section III) and a summary of test data (Section IV).

II. GENERAL DESCRIPTION

A. RF Source

The RF Source is a completely enclosed High Power Microwave generator capable of providing 1200 watts of CW RF power at 2450 MHz. The source consists of a magnetron tube, power supply, blower, and associated protection and interlock circuits. This source, when used with its external circulator/load is fully protected against all possible load mismatches.

B. Cylindrical Cavity

The purpose of the cylindrical cavity is to receive energy from the high-power S-band source, and to couple the energy into a plasma tube centered within the cavity. A sketch of the cavity is given in Figure 1. The outer conductor is made of brass tubing, 4.5 inches ID. The useable electrical length of the cavity is 32 inches and the overall length is about 40 inches. A sliding short is provided on one end of the cavity so that the electrical length can be varied; electrical contact is provided by a simple threaded joint, covered with conductive grease.

The openings in the end walls of the cavity are one inch in diameter, providing a clear optical aperture of one inch. The one inch diameter extension tube on each end, acts as a cutoff waveguide, to highly attenuate the microwave signal, and thus prevent leakage from the open ends. The three inch length provides an attenuation of greater than 100 dB.

The cavity can be operated in several different modes in order to evaluate, and ultimately to maximize the coupling efficiency to the plasma. The cylindrical waveguide modes which can be propagated within the cavity are the TE-11 and TM-01 modes. In each case,

the cavity can be configured to operate in a resonant condition (unterminated) or a travelling wave condition, with the output terminated.

It should be noted that, depending on the nature of the plasma, the center tube containing the plasma may appear more or less conductive, in which case the cavity can propagate in the TEM mode essentially as a coaxial line. The field configuration in this case, is virtually the same as the TM-01 mode, but the propagation velocity will be different.

A listing of the possible propagation modes, considering the cavity as either a cylindrical waveguide or a coaxial line, together with the guide wavelengths, is given below:

<u>Mode</u>	<u>Guide Wavelength (inches)</u> <u>(freq. = 2450 MHz)</u>
TE-11, circular wg	6.2
TM-01, circular wg	8.3
TEM, coaxial	4.8
TE-11, coaxial	5.6 (approx.)

Since the guide wavelength of each of the modes is different, the length of the cavity must be adjusted for resonance in each case. The guide wavelength will also vary depending on the nature of the plasma. Therefore, in order to assure a resonant condition for any possible plasma state, the range of adjustment is equal to one-half guide wavelength in the TM-01 mode (≈ 4.2 inches).

C. Test Setup

A block diagram of the feed network for coupling the RF energy from the source to the cavity is shown in Figures 2 and 3. The objective was to provide maximum flexibility for laboratory experimentation, utilizing components selected for simplicity and low cost, with size and weight of secondary importance.

A waveguide feed network, shown in Figure 2, is used for the resonant cavity mode of operation, and can also be used for the travelling wave mode for excitation of the TM-01 mode or a single (linearly-polarized) TE-11 mode (Figure 3a).

The coaxial feed network, shown in Figure 3b is used only for the travelling wave mode, and can be used to excite the TM-01 mode or crossed TE-11 modes for circular polarization.

For both feed networks, the output of the high power source is coupled to a circulator/load combination which isolates the source from any reflections from the cavity. The circulator is followed by a dual directional coupler used to measure both incident and reflected power. The coupler is followed by a triple stub tuner used to match the impedance looking into the cavity, in the resonant mode. The signal is then coupled to either the sum port or the difference port of a Magic-Tee Hybrid, for either in-phase or anti-phase excitation of the cavity, corresponding to excitation of the TM-01 and TE-11 modes respectively. Flexible waveguides carry the power from the hybrid to the cavity when the waveguide feed is used.

With the coaxial feed network, waveguide-to-coax transitions are connected to the hybrid and these are in turn connected through semi-rigid coaxial cable to coaxial probes mounted in the cavity walls. With the coaxial feed, the cavity must be terminated on the opposite end; this is accomplished by four separate probes connected to high power loads by semi-rigid coaxial lines.

To excite the circular polarization mode, two coaxial hybrids are connected to the outputs of the Magic-Tee hybrid to form four outputs. These are connected to four input probes in the cavity wall, by coaxial lines, to provide quadrature phase excitation of crossed TE-11 modes.

A photo of the cavity and waveguide feed is given in Figure 4.

III.

OPERATION

A. RF Source

The RF Source is connected as shown in Figure 2. The source should never be operated without a circulator/load connected to its output, since severe damage to the magnetron tube can occur due to high VSWR. The source front panel consists of the following controls with its associated functions: (See photo in Figure 5.)

Power On/Off	Turns on AC power and also provides 25 amps of circuit protection
Power, Pilot Light (amber)	Indicates presence of AC power
Ready, Pilot Light (amber)	Indicates 60 second delay after AC power is turned on - RF power can now be activated

RF On, Pilot Light (red)	Indicates RF power is active
Over Temp, Pilot Light (red)	Indicates a high temperature condition exists in the magnetron tube when RF On, Start button is depressed. RF cannot be activated under this high temperature condition. If RF is active when a high temperature condition occurs, the RF power will automatically be turned off.
Water Shut-Off, Pilot Light (red)	Indicates water flow to circulator is not adequate for proper cooling when RF On, Start button is depressed. RF cannot be activated under this condition. If the RF is active when low water flow condition occurs, the RF power will automatically be turned off.
Start Button	Start button activates RF power, only if no high temperature condition exists and water flow rates are adequate.
Stop Button	Stop button turns off RF power
Water Flow Control Connector	Connects the circulator water flow sensor to the RF source

The circulator is water-cooled and protected via a water flow sensor inter-lock. A flow rate of at least 0.5 gal/min is required to properly cool the circulator. Should the flow rate drop below 0.5 gal/min the RF power output will be interrupted. Indication of this fault will be shown by the (red) water Shut-Off Pilot Light when the RF is reactivated by RF On, Start Button. The waveguide circulator load should always be operated with an air flow in order to prevent overheating of the load.

A block diagram of the RF source is shown in Figure 6, and a parts list is given in Figures 7a, b, c. The status of the magnetron tube can be checked by breaking the connection at TPI and placing a 0-1 DC ampmeter and 0-5 KV DC voltmeter at this point. Typical readings are as shown on the schematic diagram.

B. Cylindrical Cavity

The cylindrical cavity can be configured for operation with either a waveguide feed or a coaxial feed network. The operating procedure for each is described below.

1. Waveguide Feed

For waveguide excitation, the cavity end-plate with integral waveguide flanges is used. This end-plate is attached to the end cavity by screws; the apertures in the plate provide the coupling to the cavity.

For the resonant cavity mode, all of the coaxial probes are removed, and the openings in the cavity walls are covered with the small plates provided. For the travelling wave mode, the four probe covers near the waveguide feed are left on, but the covers on the opposite end are removed and replaced by the coaxial probes, for connection to the external high power loads.

The position of the sliding short circuit is adjusted, by rotating the extender tube on the output end. In the resonant cavity mode, the short circuit position is adjusted for resonance, as discussed in Part C below; for the travelling wave mode, the short is set to a position of 1-3/4 inches on the scale provided which provides the best match for the coaxial probes.

2. Coaxial Feed

For coaxial excitation, the endplate with the waveguide flanges is removed and replaced with the solid, flat endplate. Depending on the desired mode of excitation, either two or four coaxial probes are used on the input end. For excitation of either the TM-01 mode, or a single (linearly polarized) TE-11 mode, only two probes are used, displaced 180° from each other. For excitation of crossed TE-11 modes, all four input probes are used. It should be noted that for coaxial excitation, regardless of the mode being excited, all four terminating probes must be used with their associated loads attached. Failure to terminate the cavity, when using coaxial excitation, can result in voltage breakdown at the probes and/or overheating of the coaxial feed lines.

C. Test Setup and Tuning Procedure

The test setup and tuning procedure are discussed with reference to Figures 2 and 3 described earlier. The portion of the setup from the source to the Magic-Tee Hybrid, is the same, regardless of whether waveguide or coaxial excitation is to be used. The circulator and its load, the dual directional coupler, the triple-stub tuner and the hybrid are all fabricated in WR-284 waveguide, and are assembled in the conventional way.

1. Waveguide Feed - Resonant

Excitation of a particular propagation mode in the cavity is determined by the particular hybrid ports to which the source is connected as follows:

TM-01 Sum Port driven
 Difference port terminated

TE-11 Difference port driven
 Sum port terminated

In either case, the colinear ports of the hybrid are connected to the cavity input ports by means of the flexible waveguide.

The procedure for tuning the network for optimum coupling in the resonant mode, is as follows:

- (1) Connect power meters to the forward and reflected power ports of the dual directional coupler, and to the directional coupler in the load port of the hybrid.
- (2) Turn the middle screw of the triple stub tuner to insert the stub all the way in.
- (3) Turn the power on, and observe the incident and reflected power; the reflected power will typically be almost equal to the incident.
- (4) Move the sliding short circuit (by turning the extender tube as described above), and watch for a reduction in reflected power. Set the short circuit to the position for minimum reflection.

- (5) Readjust the triple stub tuner, first the center stub and then the others, to minimize the reflected power.

With the short circuit and the tuner properly adjusted, the reflected power and the power out of the isolated port of the hybrid should each be 20% of the incident, or less.

If either the reflected power or the isolated port power can not be adjusted to be less than 20%, then the cavity may be tuned to a spurious mode. In this case, readjust the sliding short circuit to search for another resonance, i.e. a dip in reflected power, and repeat steps (4) and (5).

The resonant condition is quite critical because of the high Q of the cavity, especially when unloaded. Also, when a plasma is present in the cavity, the resonant condition will vary with the condition of the plasma, and so the sliding short and the stub tuner will probably require re-tuning after the plasma is excited.

2. Waveguide Feed - Travelling Wave

The procedure for tuning the setup in the travelling wave mode is as follows:

- (1) Connect high power terminations to all four output coaxial probes
- (2) Set the sliding short to 1-3/4 inches on the scale.
- (3) Adjust the tuner so that all three probes are all the way out.
- (4) Turn the power on and observe the incident, reflected and isolated power. If the reflected and isolated power are below 20%, no additional tuning is required.
- (5) If the reflected power is too high, the tuner can be adjusted to minimize the reflected power.

3. Coaxial Feed

The coaxial feed network may be used in any of the travelling wave modes. However, since the TM-01 and the single TE-11 mode can be excited with the waveguide feed, use of the coaxial feed is recommended only for excitation of the circularly polarized mode, i.e. crossed TE-11 modes in quadrature phase.

For the circularly polarized mode, the waveguide-to-coax adaptors are connected to the colinear ports of the Magic-Tee hybrids. Two coaxial hybrids are in turn connected to the adaptors; the adaptors feed the sum ports, and the difference ports are terminated as shown in Figure 3. One pair of coaxial cables are connected from one hybrid to two of the coaxial probes (opposite each other). The other hybrid is connected to the other two coaxial probes, using a pair of cables which have been cut for 90° shorter length at 2450 MHz.

- (1) With the setup configured as described above, and with all four output probes terminated, adjust the tuner so that all three stubs are all the way out.
- (2) Turn on the power and observe the incident and reflected power.
- (3) The circuit should be self-calibrated in this case. The tuner should not be adjusted from its maximum out position in this case, since this would create a risk of breakdown or overheating of the coaxial feed network.

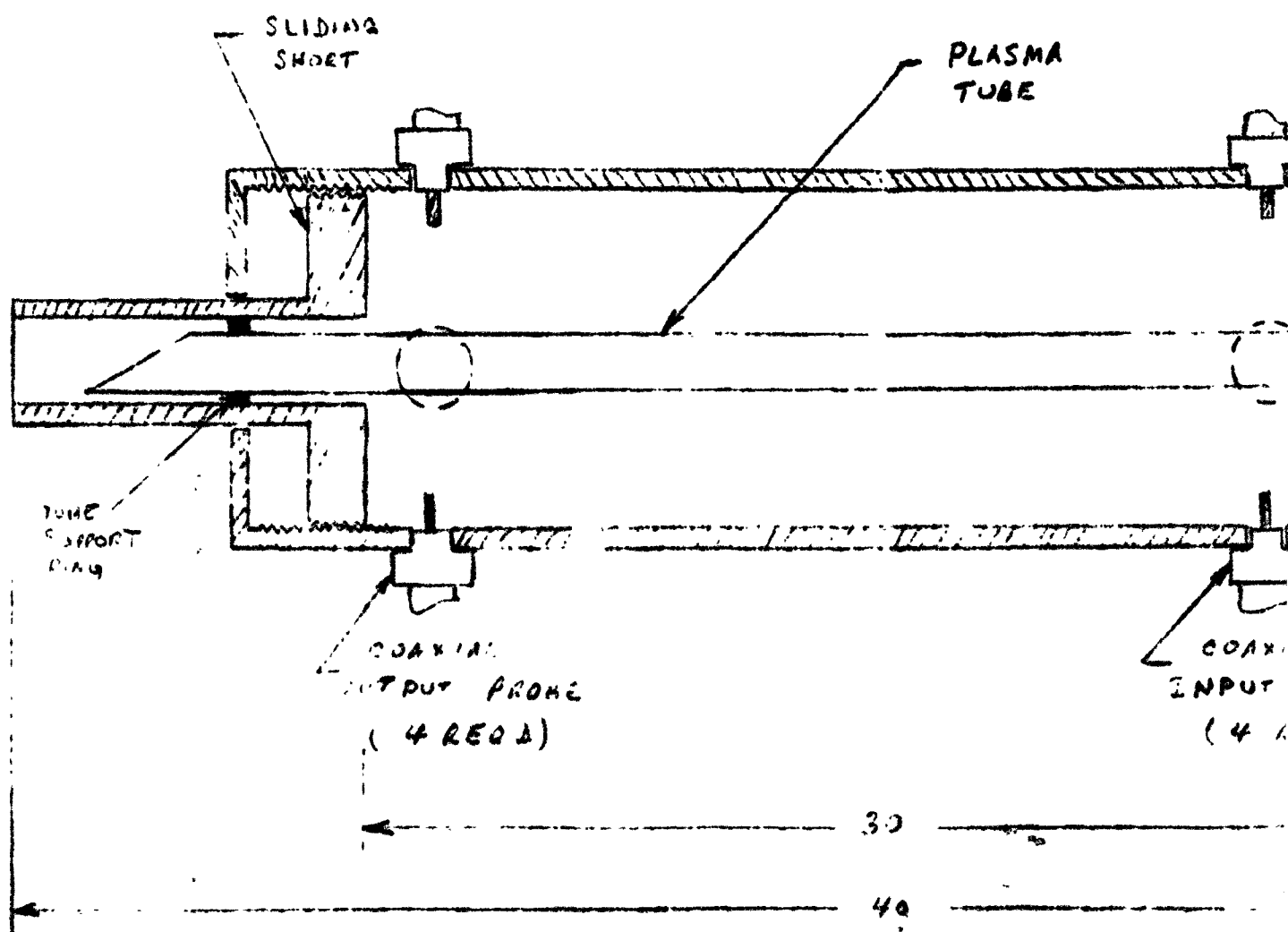
IV.

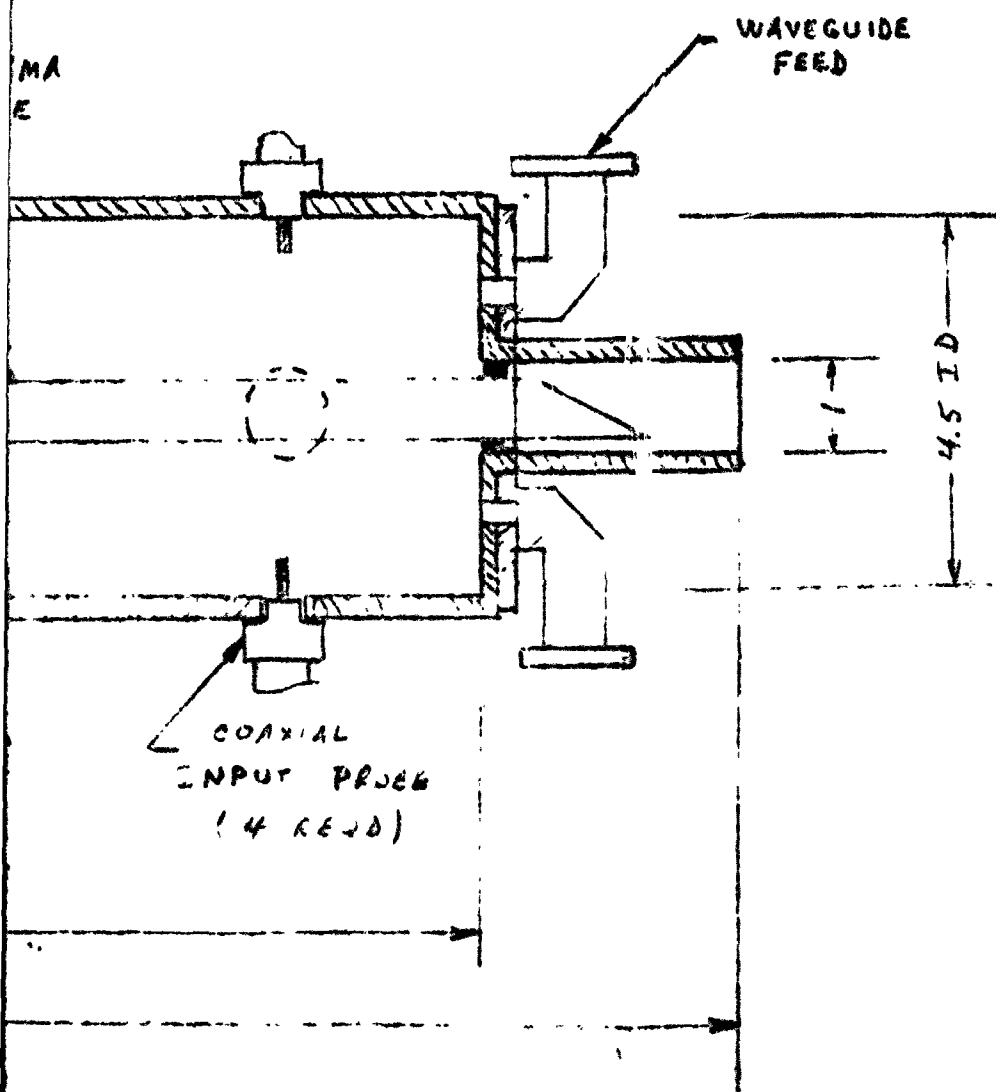
TEST DATA

A variety of low-power and high-power measurements were made to characterize the performance of the cavity in the various modes. The low-power measurements included swept frequency plots, of input reflection for the resonant condition, and of input reflection and transmission for the travelling wave case. Transmission is measured from the input to each of the output probes (individually); since there are four probes, -6 dB is equivalent to complete transmission. A listing of the test data is given below:

High power measurements were made with the RF high power source at a single frequency of 2450 MHz.

<u>Sheet No.</u>	<u>Parameter Measured</u>	<u>Cavity Configuration</u>
4-1	Reflection	TE-11, Resonant, Empty
4-2	Reflection	TE-11, Resonant, w Pyrex tube
4-3	Reflection	TM-01, Resonant, Empty
4-4	Reflection	TM-01, Resonant, w Pyrex tube
4-5	Reflection	(same as 4-4, expanded scale)
4-6	Transmission	TE-11, Travelling Wave, Empty
4-7	Reflection	TE-11, Travelling Wave, Empty
4-8	Transmission	TM-01, Travelling Wave, Empty
4-9	Reflection	TM-01, Travelling Wave, Empty
4-10	Summary of high power measurements	





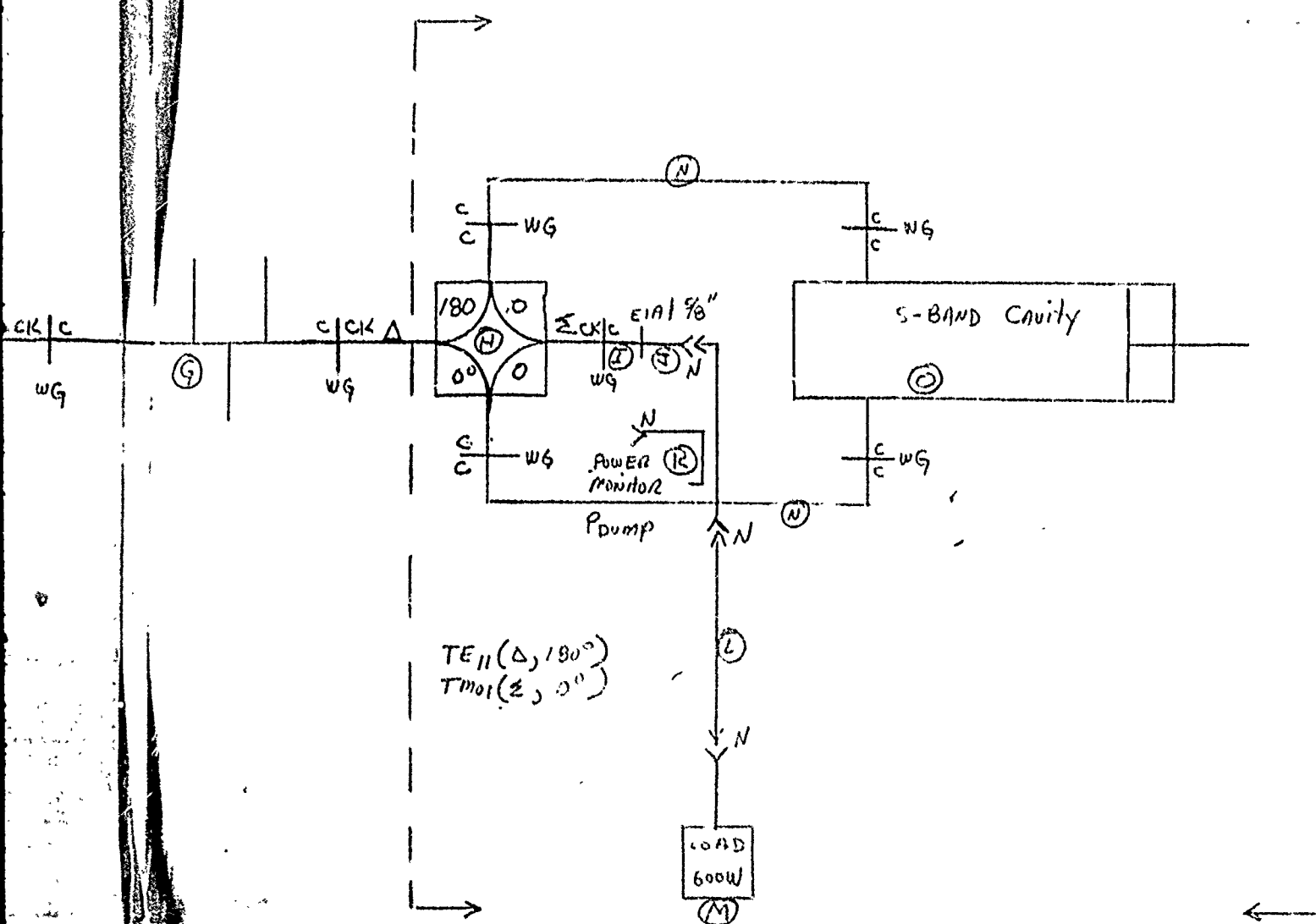
2

FIG. 1 - SKETCH OF
CYLINDRICAL CAVITY



176	A RF SOURCE	ITT BUILT
	B CIRCULATOR, WAVEGUIDE + WATER FLOW SENSOR	MEPRIMAC # FCW/521, PRESSURE CON
	C LOAD, WAVEGUIDE 600WATT	ARF PRODUCTS # 1D403
	D AIR BLOWER	CUSTOMER Supplied
	E DIRECTIONAL COUPLER (SIDEWALL WAVEGUIDE)	ITT Supplied
	F TWIST, WAVEGUIDE	ITT Supplied
	G TRIPLE STUB TUNER, WAVEGUIDE	GERLING MOORE #4037
	H 4-PORT HYBRID TPE, WAVEGUIDE	STATHORS # M352S
	I TRANSITION, WR284 to EIA 1 7/8"	GERLING MOORE # 4028
	J TRANSITION, EIA 1 7/8 to TYPE N	ANDREW # 2261A
	K DIRECTIONAL COUPLER, COAXIAL	MACCA # 715-30-4
	L CABLE ASSEMBLY, 7/8"	ANDREW # 25817-5
	M LOAD COAXIAL, 600WATT	BIRD #8401
	N WAVEGUIDE FLEXIBLE (TWO)	GERLING MOORE # 4017
	O S-BAND CAVITY	ITT BUILT

		REVISION
ZONE	LTR	DESCRIPTION



7103

Sampling = 27 AT 2.45618

1

REVISIONS

DESCRIPTION

DATE

APPROVED

Cavity/
TEII MOBLE
TMOJ



3

SYSTEM PARTS LIST

- 1 SIG
- A RF SOURCE
 - B CIRCULATOR, WAVEGUIDE + WATER FLOW SENSOR
 - C LOAD, WAVEGUIDE 600WATT
 - D AIR BLOWER
 - E DIRECTIONAL COUPLER (SIDEWALL WAVEGUIDE)
 - F TWIST, WAVEGUIDE
 - G TRIPLE STUB TUNER, WAVEGUIDE
 - H 4-PORT HYBRID TPE, WAVEGUIDE
 - I TRANSITION, UP244 TO ETA 1 1/8"
 - J TRANSITION, ETA 1 1/8 TO TYPE N
 - K DIRECTIONAL COUPLER, COAXIAL
 - L COIL ASSEMBLY, 7/8"
 - M LOAD COAXIAL, 600WATT
 - N WAVEGUIDE FLEXIBLE (TWO)
 - O PLAIN CAVITY

ITT BUILT

MERRIMAC # FCW1521, PRESSURE CONTR
APF PRODUCTS # 1D403

CUSTOMER SUPPLIED
ITT SUPPLIED

ITT SUPPLIED
GERLING MOORE #4037

STRUTHERS # M3525
GERLING MOORE #4028

ANDREW # 2261A
MECCA # 715-10-4

ANDREW # 25817-5
BIRD # 3401

GERLING MOORE #4017
ITT BUILT

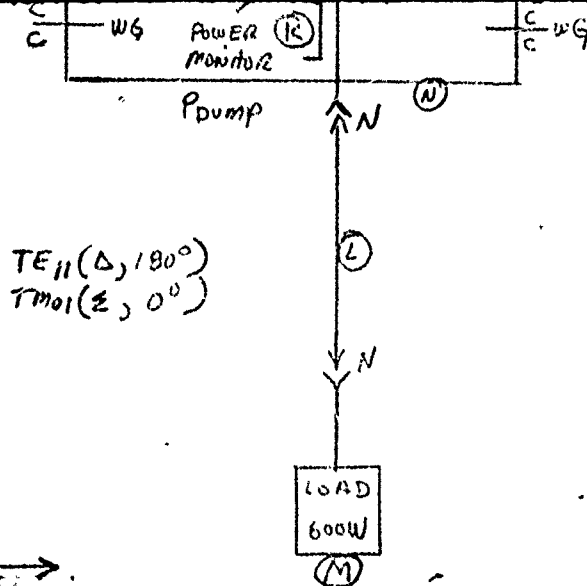
ENGINEERING CHECK LIST

- WET CHIBS ☐ LOCATE IN Q10. FREEMAND SKETCHING PREFERRED.
1. FEA ACUTE SYMBOLS FUNCTIONALLY AROUND EACH STAGE.
2. FEA STAGES IN LAYERS FROM LEFT-TO-RIGHT
3. FEA LAYERS FROM TOP-TO-BOTTOM.
- SIGNAL FLOW ☐ DATA INPUTS AT LEFT, OUTPUTS AT RIGHT (PREFERRED)
OR INPUTS AT TOP, OUTPUTS AT BOTTOM, OR ANY
COMBINATION OF THE TWO ABOVE.
- SYMBOLS ☐ 1. FEA IT SYMBOLS PER USA STD Y32 FOR DETAIL, Y31
FOR GENERAL SYMBOLS PER USA STD Y32 FOR DETAIL, Y31
FOR GENERAL SYMBOLS PER USA STD Y32 FOR DETAIL, Y31
FOR GENERAL SYMBOLS PER USA STD Y32 FOR DETAIL, Y31

- REF DESIG ☐ IDENTIFY EACH SYMBOL BY REFERENCE DESIGNATION PER
USA STD Y32 16 FOR DETAIL SEE ESM.
ASSIGN REF. DESIGN NUMBERS CONSECUTIVELY FROM
LEFT TO RIGHT IN FUNCTIONAL SEQUENCE.
- PARTS IDENT ☐ SPECIFY RESISTANCE, CAPACITANCE AND INDUCTANCE VALUES.
USE THE FORM OF FEWEST DIGITS.
SCHEMATIC IDENTITIES MUST AGREE WITH ELECTRICAL PARTS LIST
- OTHER INFO ☐ ASSIGN FUNCTIONAL IDENTIFICATION TO PARTS, STAGES AND CIRCUITS.
INDICATE MECHANICAL LINKAGE, PUT ADJUSTMENT AND OPERATING CONTROLS.
INDICATE SHIELDING, PAIRING AND CRITICAL GROUND.
OUTLINE TERMINAL BOARDS AND SUB ASSEMBLIES.

1

3



$TE_{11}(D, 180^\circ)$
 $TM_{01}(E, 0^\circ)$

LOAD
600W

g = 2 AT 2.45 GHz

coup 0.4 dB AT 2.45 GHz
 coup 0.2 dB AT 2.45 GHz

- NOTES (1) OBSERVE CIRCULATOR L
- (2) WG C WILSON E C
- (3) WG CK WILSON E C

INSTRUCTIONS

NOTES:

- PARTIAL REFERENCE DESIGNATIONS ARE SHOWN; FOR COMPLETE DESIGNATION PREFIX WITH UNIT NUMBER AND SUB-ASSEMBLY DESIGNATIONS.
- UNLESS OTHERWISE SPECIFIED:
 ALL RESISTANCE VALUES ARE IN
 ALL CAPACITANCE VALUES ARE IN
 ALL DIODES ARE
 ALL TRANSISTORS ARE
 ALL INTEGRATED CKTS ARE

PREPARED IN ACCORDANCE
WITH MIL STD 100

GROUP	SIZE	NEAT ASSY	USED ON
G			
C			
G			
GI			
GROUP	SIZE	APPLICATION	

CONTRACT DAAK 70-79-C-0171

APPROVALS SIGNATURE & DATE

DRAWN *J. J. R. Smith*

CHECKED *J. J. R. Smith*

MECH *J. J. R. Smith*

ELECT *J. J. R. Smith*

STDS *J. J. R. Smith*

1 OF 1

ITT AVIONICS
DIVISION

28527

SCALE CATEGORY

WG



- NOTES ① OBSERVE CIRCULATOR Polarity
 ② WG C WAVEGUIDE COULR
 ③ WG CK WAVEGUIDE COULR

RED IN ACCORDANCE MIL STD 100		CONTRACT DMR 70-79-C-0171		AVIONICS DIVISION		NUTLEY, NEW JERSEY	
APPROVALS SIGNATURE & DATE		TEST SET-UP FIG. 2					
DRAWN	<i>[Signature]</i>						
CHECKED	<i>[Signature]</i>						
MECH							
ELECT							
USED ON	SIDS	C 28527 SCALE CATEGORY SHEET REV					
APPLICATION	E OF #						
	OTHER						

SYSTEM PARTS LIST

REF DESIGN

H 4-PORT HYBRID TEE, WAVEGUIDE

STRATHENS #M3523

I Transition, WR284 to EIA 1 1/8"

GERLING MOORE #4028

J Transition, EIA 1 1/8" to TYPEN

ANDREW #2261A

K Directional Coupler, COAXIAL (Two)

MCCA #715-30-4 C/CK

L CABLE ASSEMBLY, 7/8"

ANDREW #25817-5 WG

M LOAD, COAXIAL, 600WATT

BIRD #8401

N WAVEGUIDE FLEXIBLE (Two)

GERLING MOORE #4017

O S-BAND CAVITY

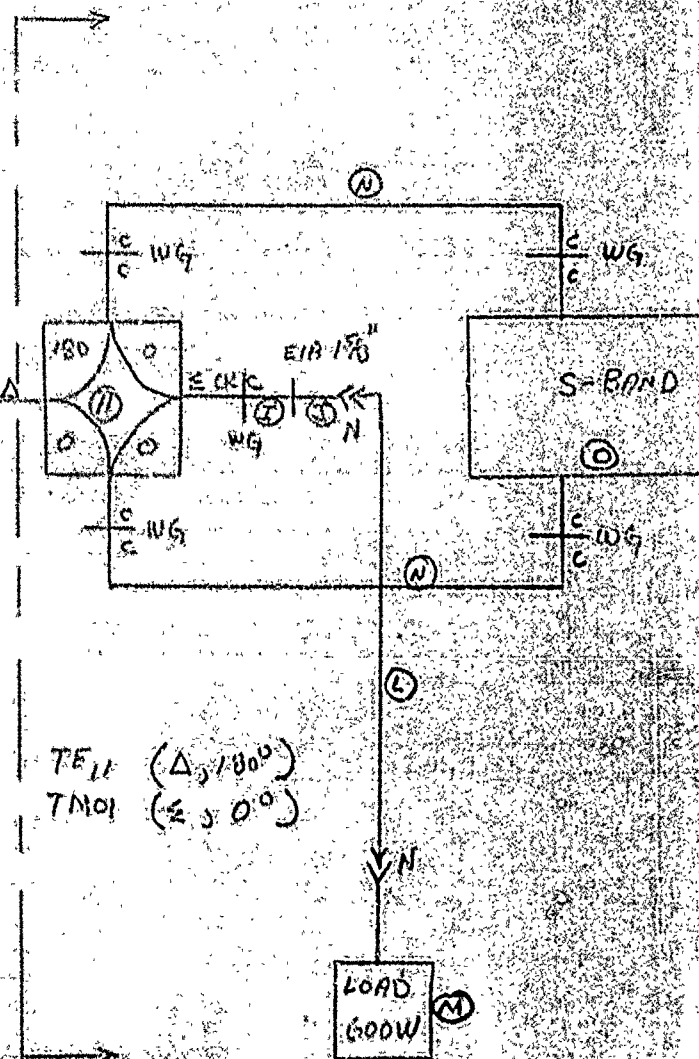
ITT BUILT

P CABLE ASSEMBLY, 1/2" (Four)

ANDREW #39760-3

Q LOAD, COAXIAL, 250 WATT (Four)

BIRD #8141



TE₁₁ (Δ , 180°)
TM₀₁ (Σ , 0°)

SYSTEM PARTS LIST

DESIGN

H 4-PORT HYBRID TEE, WAVEGUIDE

STRATHENS #M3523

I Transition, WR284 to EIA 1 1/8" (Two)

GERLING MOORE #4028

J Transition, EIA 1 1/8" to TYPEN (Two)

ANDREW #2261A

K Directional Coupler, COAXIAL (Two)

MCCA #715-30-4 C/CK

L CABLE ASSEMBLY, 7/8"

ANDREW #25817-5 WG

M LOAD, COAXIAL, 600 WATT (Two)

BIRD #8401

NOT USED

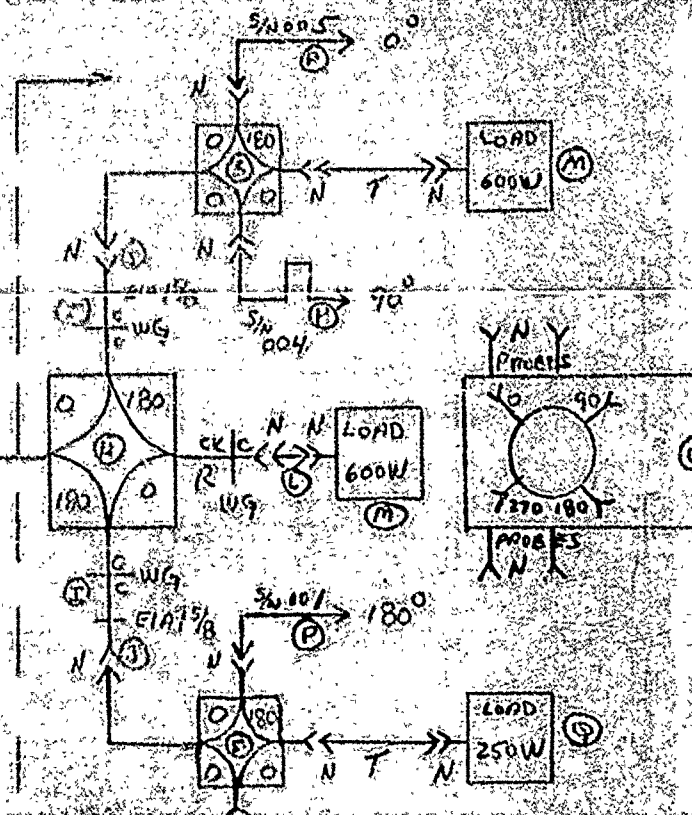
N S-BAND CAVITY

ITT BUILT

P CABLE ASSEMBLY, 1/2" (Four)

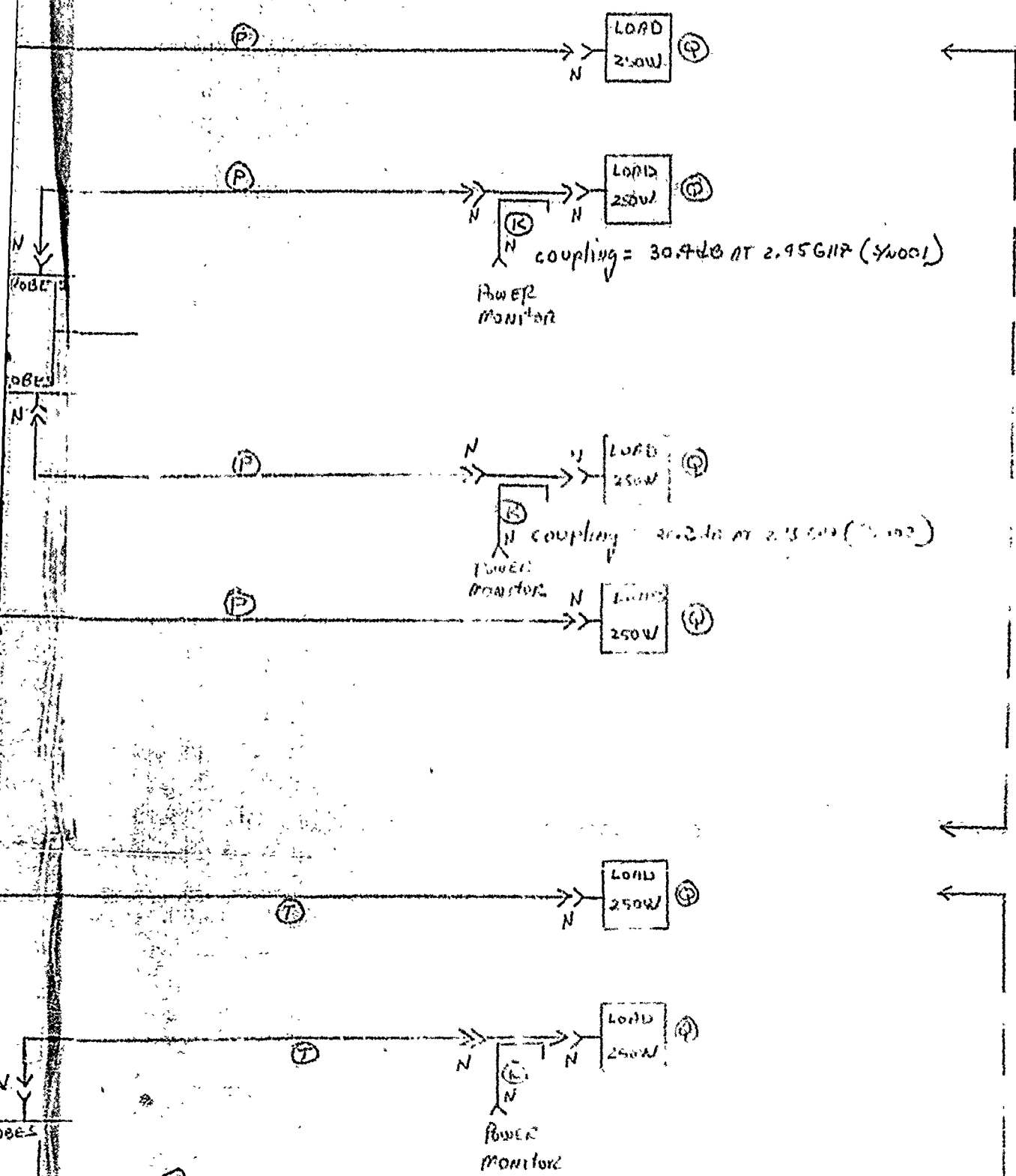
ANDREW #39760-3

NOTE: OBSERVE CABLE SW FOR PROPER PHASE POLARITY



ORM

REVISIONS		
ZONE	LTR	DESCRIPTION



TRAVELING W
TEH
TMOI
(a)

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROV

0. AT 2.45 GHz (50001)

TRAVELING WAVE
TEH MODE
TMOI

(a)

0. AT 2.13 GHz (50002)

1. 16

4- BIT HYBRID TWT, WAVEGUIDE

STRUTHERS #M3525

TRANSITION, WAVEGUIDE TO LINE 1/8" (TWO) GERLING #M3525

TRANSITION, EIA 1 1/8" TO TYPE N (TWO) ANDREW #2261A

1. DIRECTIONAL COUPLER, COAXIAL (TWO)

MECCA #715-20-4 C/C

2. CABLE ASSEMBLY, 1/8"

ANDREW #25817-5 W/G

3. LOAD, COAXIAL, 600 WATT (TWO)

BIRD #8401

4. NOT USED

5- RING CAVITY

CABLE ASSEMBLY, 1/2" (FOUR)

JTT BUILT

ANDREW #39760-3

6. OBSERVED CABLE SW. FOR

POWER PHASE POLARITY

7. COAXIAL, 750 WATT (FIVE)

BIRD #8141

8. TRANSITION, WAVEGUIDE TO TYPE N

WAVELINE #201-AT

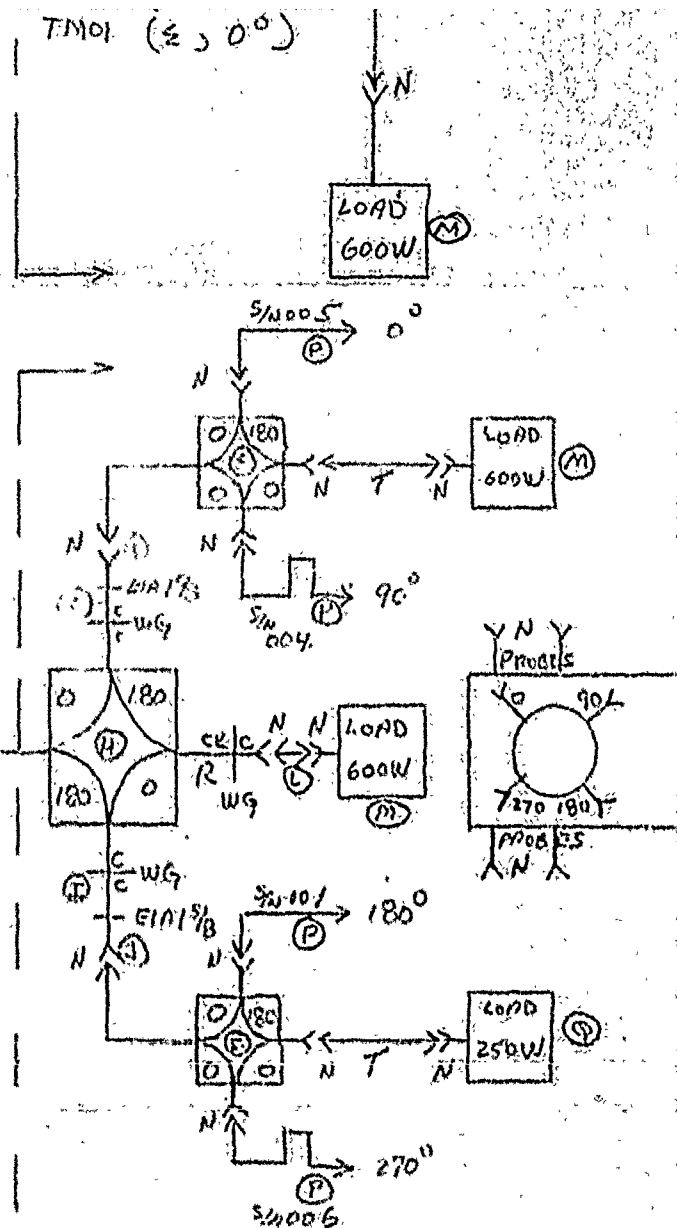
9- BIT HYBRID TWT, COAXIAL (TWO)

MECCA #61-47601

10. CABLE ASSEMBLY, COAXIAL (SIX)

W/G 21 1/2" JTT BUILT

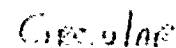
TEU (A, 100)



ENGINEERING CHECK LIST

- SKETCHING: ☐ LOCATE ON GRID. FREEHAND SKETCHING PREFERRED. LOCATE CIRCUIT SYMBOLS FUNCTIONALLY AROUND EACH STAGE. CONNECT STAGES IN LAYERS FROM LEFT-TO-RIGHT. ARRANGE TWO OR MORE LAYERS FROM TOP-TO-BOTTOM.
3. SIGNAL FLOW: ☐ LOCATE INPUTS AT LEFT, OUTPUTS AT RIGHT (PREFERRED), OR INPUTS AT TOP, OUTPUTS AT BOTTOM, OR ANY COMBINATION OF THE TWO ABOVE.
- SYMBOLS: ☐ USE CIRCUIT SYMBOLS PER USA STD Y37.2 FOR DETAIL, SEE ENGINEERING STANDARDS MANUAL. USE LOGIC SYMBOLS PER USA STD Y37.13 FOR DETAIL, SEE ENGINEERING STANDARDS MANUAL.

- REF DESIG: ☐ IDENTIFY EACH SYMBOL BY REFERENCE DESIGNATION PER USA STD Y37.16. FOR DETAIL SEE ESM. ASSIGN REF. DESIG NUMBERS CONSECUTIVELY FROM LEFT TO RIGHT IN FUNCTIONAL SEQUENCE.
- PARTS IDENT: ☐ SPECIFY RESISTANCE, CAPACITANCE AND INDUCTANCE VALUES. USE THE FORM OF FEWEST CIPHERS. SCHEMATIC IDENTITIES MUST AGREE WITH ELECTRICAL PARTS LIST.
- OTHER INFO: ☐ ASSIGN FUNCTIONAL IDENTIFICATION TO PARTS, STAGES AND CIRCUITS. INDICATE MECHANICAL LINKAGE, POT ADJUSTMENT AND OPERATING CONTROLS. INDICATE SHIELDING, PAIRING AND CRITICAL GROUND. OUTLINE TERMINAL BOARDS AND SUB ASSEMBLIES.



TEL

Not 3

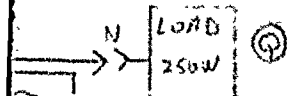
64, C

000

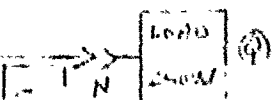
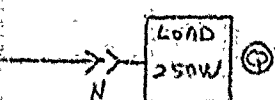
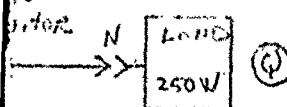
OPERATOR INSTRUCTIONS		NOTES:		PREPARED IN ACCORDANCE WITH MIL STD 100		CONTRACT DATA SYMBOL 70-14-C-017		TITLE AV	
<div style="text-align: center; font-size: 2em;">S</div>		1. PARTIAL REFERENCE DESIGNATIONS ARE SHOWN; FOR COMPLETE DESIGNATION PREFIX WITH UNIT NUMBER AND SUB-ASSEMBLY DESIGNATIONS.		G		APPROVALS SIGNATURE & DATE		TITLE DR	
		2. UNLESS OTHERWISE SPECIFIED: ALL RESISTANCE VALUES ARE IN ALL CAPACITANCE VALUES ARE IN ALL DIODES ARE ALL TRANSISTORS ARE ALL INTEGRATED CKTS ARE		G		DRAWN			
						CHECKED			
						MECH			
						ELECT			
						STDS			
				APPLICATION		E OF M			
				EXCEPT AS MAY BE OTHERWISE PROVIDED BY A SPECIAL NOTE, THIS DRAWING IS TO BE USED AS A GUIDE ONLY AND SHALL NOT BE REPRODUCED OR COPIED OR SET AS THE BASIS FOR THE MANUFACTURE OR SALE OF APPARATUS WITHOUT PERMISSION.		OTHER			
						SCALE		C 28527	

1.511 11 21-5
TMOU

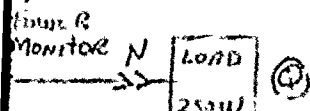
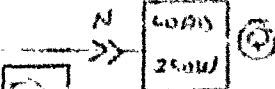
(a)



at coupling - 30-2 dB at 2.15 GHz (1/2002)



Power Monitor



Circular Polarizer
TEH Mode
(b)

NOTES

WG C 11/29/91
WG CR 11/29/91

ANCE DESIGNATIONS ARE
MPLETE DESIGNATION
IT NUMBER AND SUB-
NATIONS.
SE SPECIFIED:
E VALUES ARE IN
E VALUES ARE IN
RS ARE
D CKTS ARE

PREPARED IN ACCORDANCE WITH MIL STD-103		CONTRACT DATA TO-14 C-01		AVIONICS DIVISION		HUTLEY NEW JERSEY	
APPROVALS SIGNATURE & DATE		DRAWN		7		6	
CHECKED		MECH					
ELECT		STOS					
E OF H		ITAY		SCALE		CATEGORY	
OTHER		OTHER		28527		SHEET	

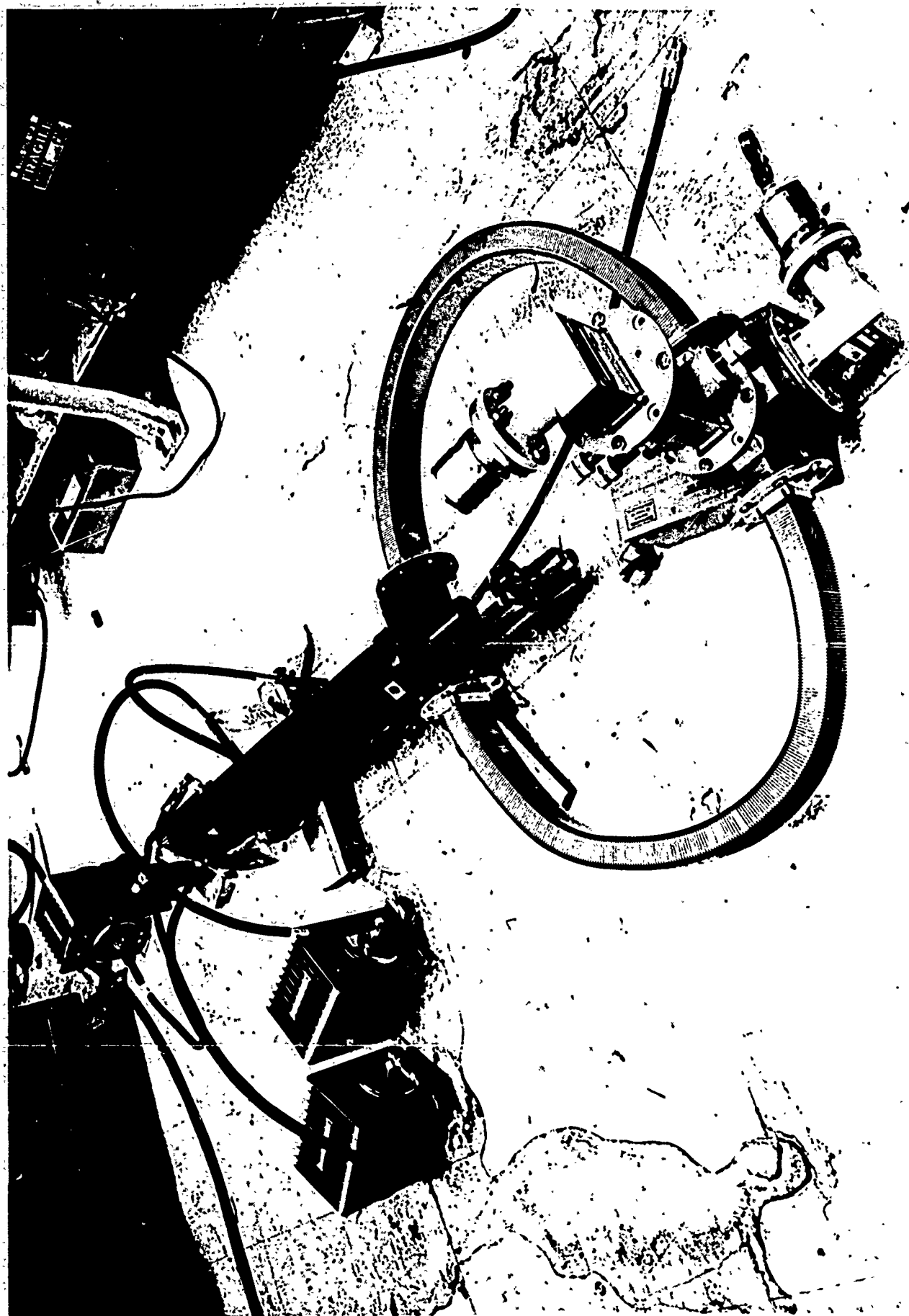
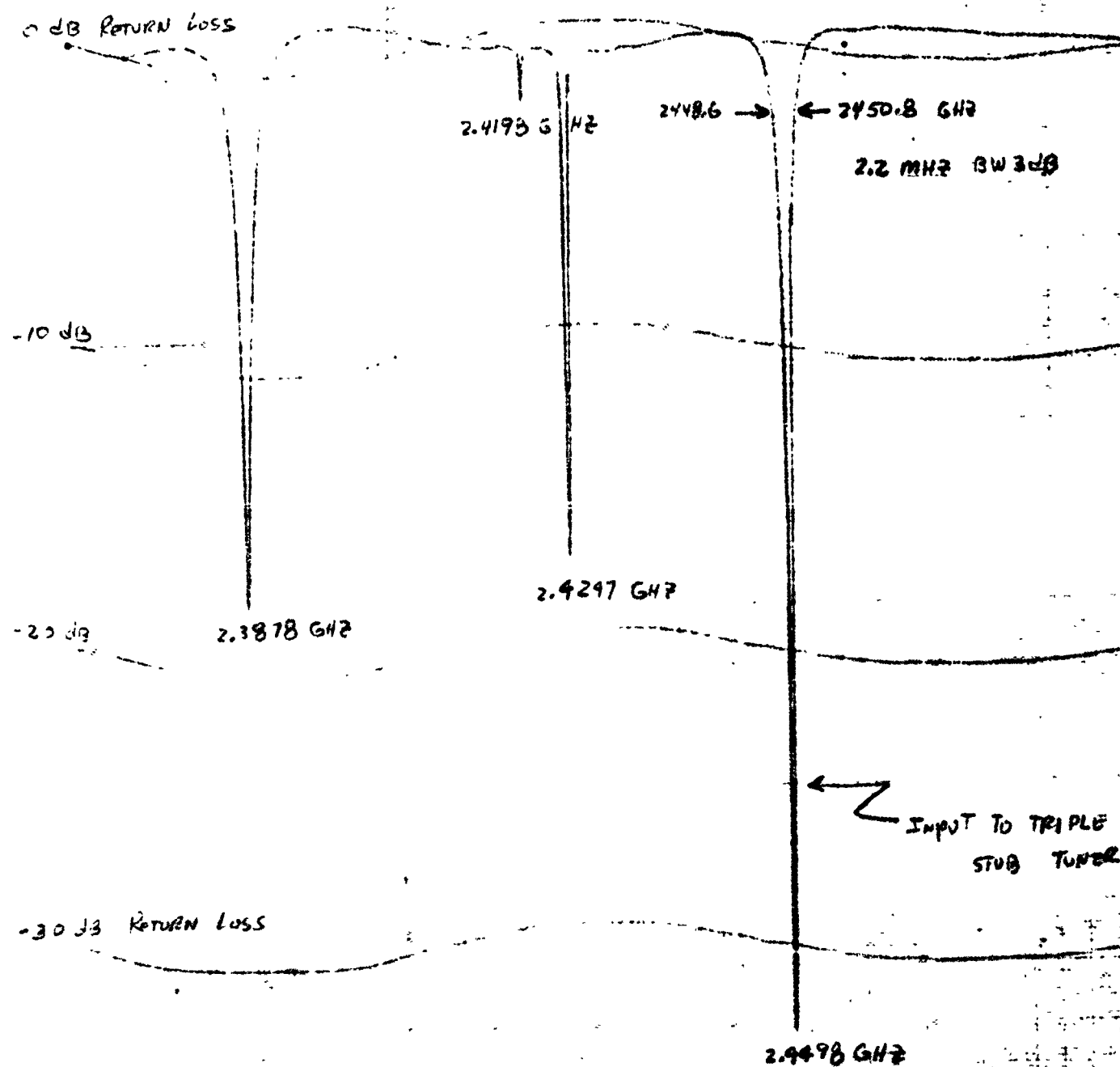
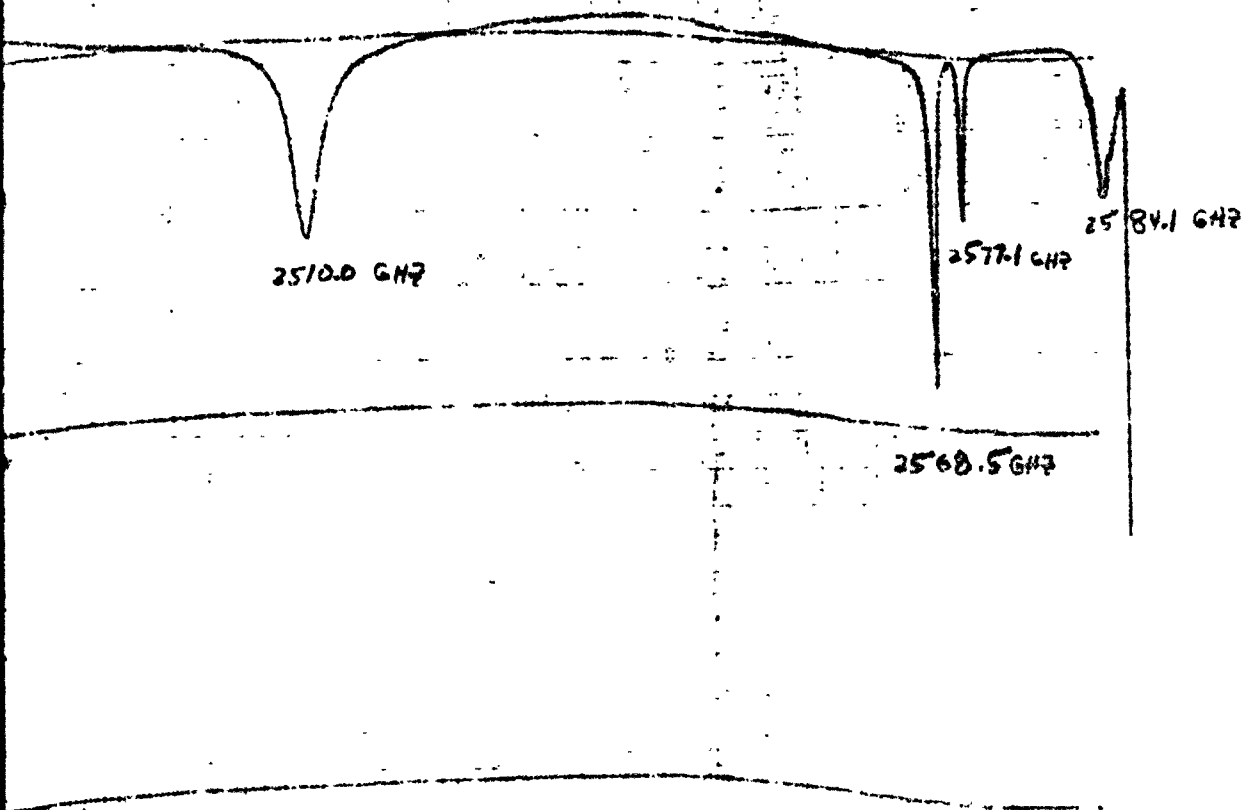


FIG 4 PHOTO OF CAVITY





PLE
UNER


RETURN	LOSS	
MODE	TE11	CAVITY (Δ MODE)
INPUT	WAVEGUIDE	
SHORT	$d = 3\frac{3}{4}''$	
CAVITY	AIR	
CONTENTS		
POWER	10 MW	
LEVEL		

FIG 4-1

0dB RETURN LOSS

-10

2.3908 GHz

2.443.6 GHz

2.448.6 GHz

50 MHz BW 3dB

2.4892 GHz

-20

POINT TO TRIPLE
STUB TUNER

-30dB RETURN LOSS

2.4462 GHz

GEG 10/17/80

2.5134 GHz

2.5787 GHz

RETURN	LOSS	
MODE	TE ₁₁	Cavity (Amplifier)
INPUT	WAVEGUIDE	
SHORT	3/16"	
Cavity	Pyrex	
Contents		
POWER	10 mW	
LEVEL		

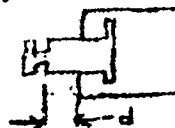
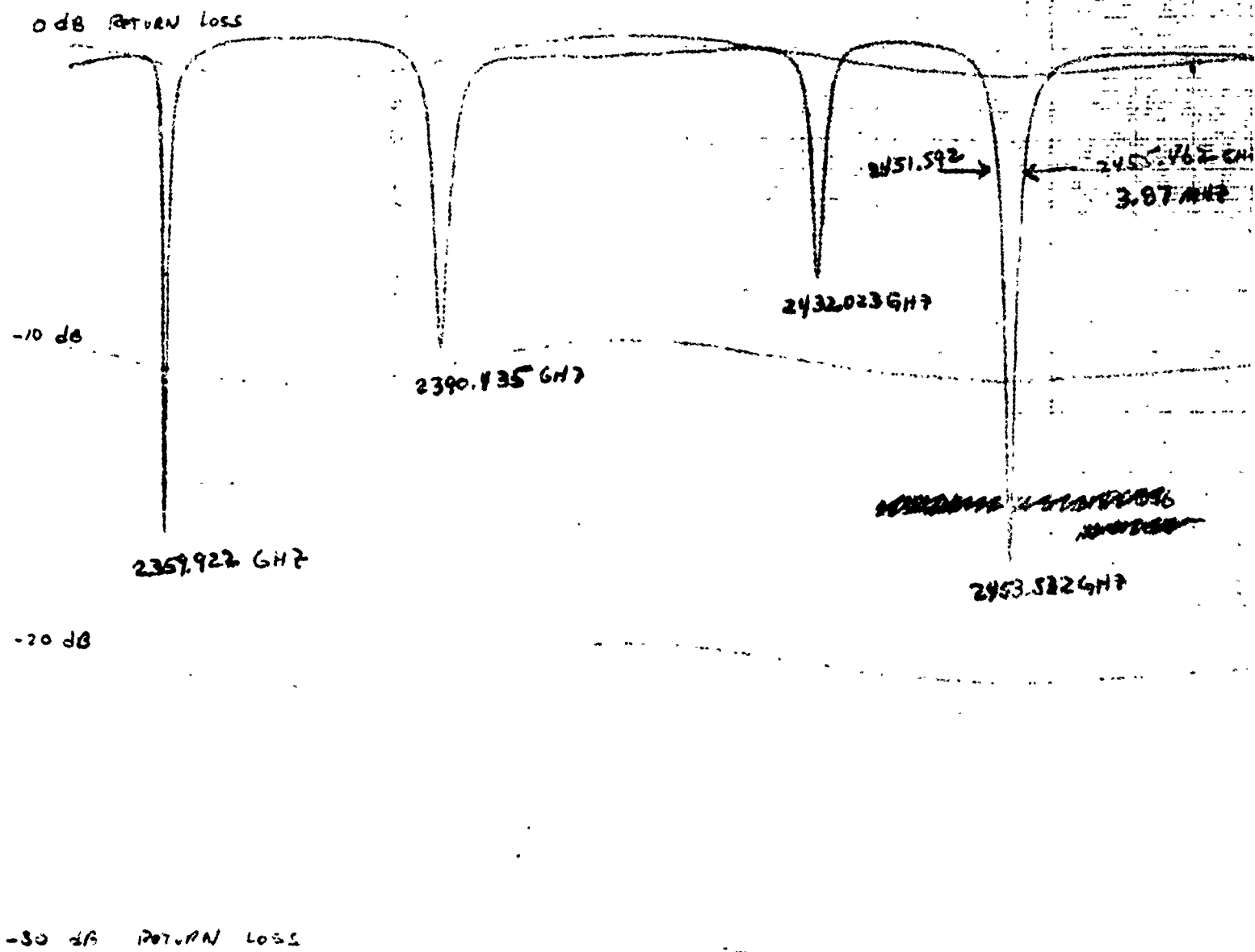


FIG 4-2

2



1
GEG 10/14/80

5.462 GHz
 BW 3 dB AT
 P_{in} = 10 mW

2506.180 GHz

2535.290 GHz

RETURN LOSS
 MODE - TM₀₁, CAVITY (2 MODE)
 INPUT WAVEGUIDE
 SHORT SECTION 4 7/8"
 CAVITY AIR
 PORTS

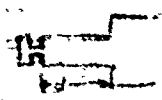


FIG 4-3

2

0 dB RETURN LOSS

10 dB

-20 dB

-30 dB RETURN LOSS

2457.011 GHz

2457.011 GHz

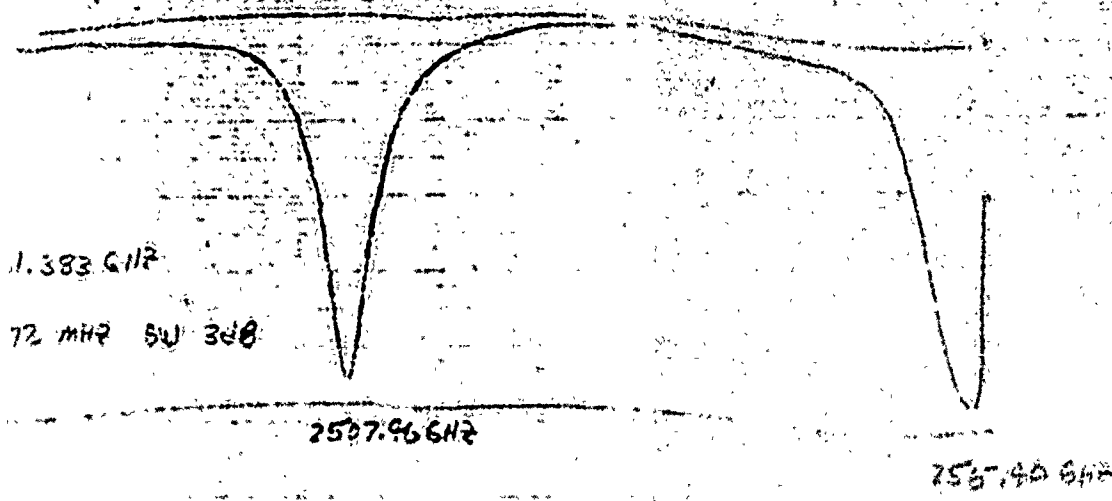
2457.011 GHz

2461.383 GHz

4.372 MHz

2459.0 GHz

INPUT TO TR
STUB TUN



TO Triple
SUB TUNER

RETURN LOSS
MODE TM₀₁ Cavity (2 mode)
INPUT WAVEGUIDE
SHORT $l = 2 \frac{3}{8}''$
Cavity MATERIAL PYREX

FIG. 4-48

0 dB RETURN LOSS

-1 dB

-2 dB

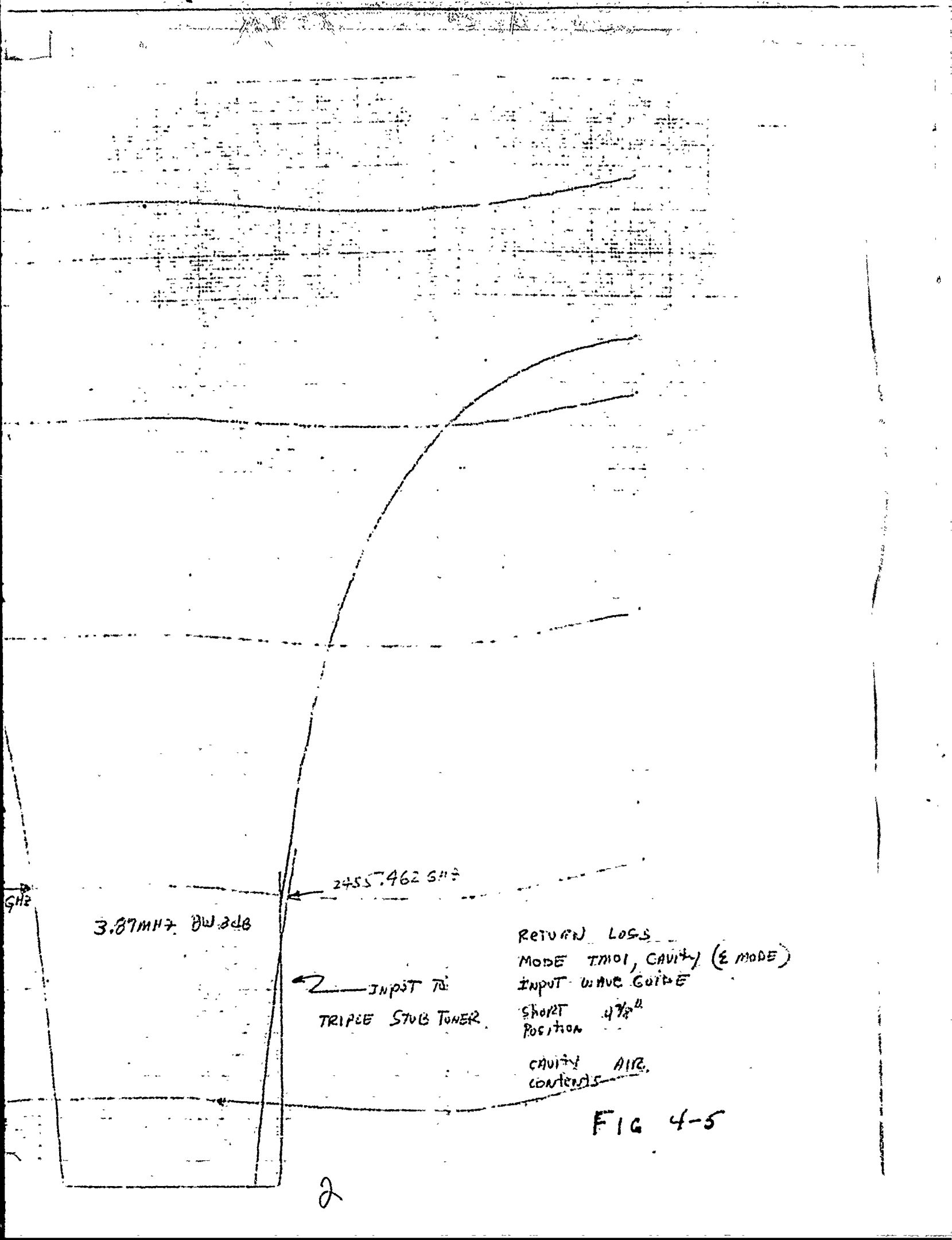
-3 dB

-4 dB RETURN LOSS

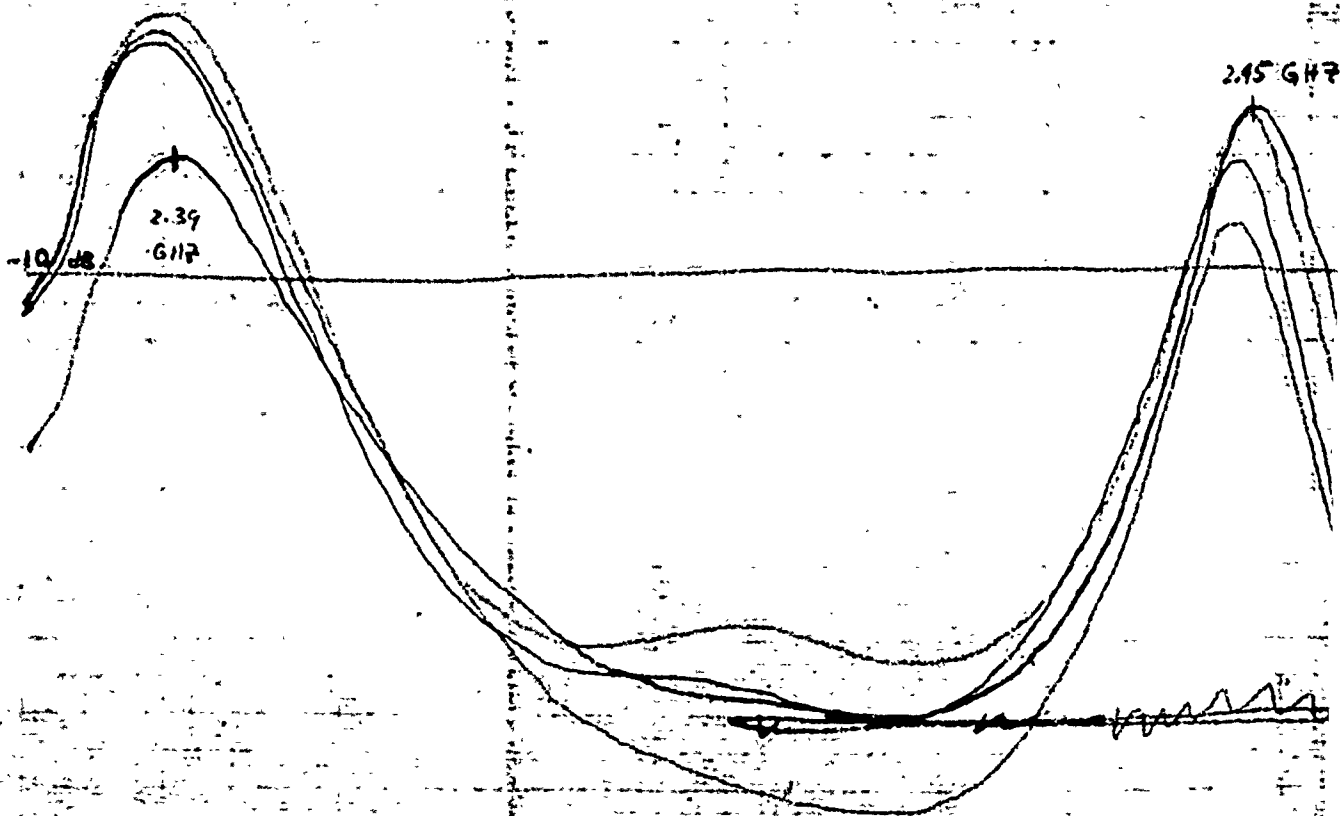
2451.572 GHz

3.87mm

GEG 10/14/80

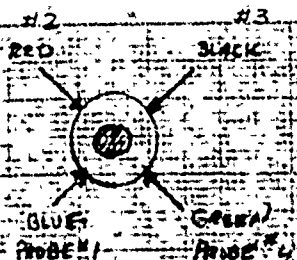


0 dB INSERTION LOSS

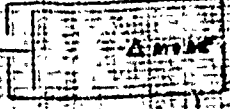


-20 dB INSERTION LOSS

GEG 11/3/80



FRONT VIEW



SIDE VIEW

INSERTION LOSS
 MODE: TE₁₁ TRAVELING WAVE
 INPUT: WAVEGUIDE
 OUTPUT: COAXIAL (FOUR)
 SWR: 2 (SCALE)
 CAVITY: AIR
 CONTROLS:

POWER LEVEL: 10mW

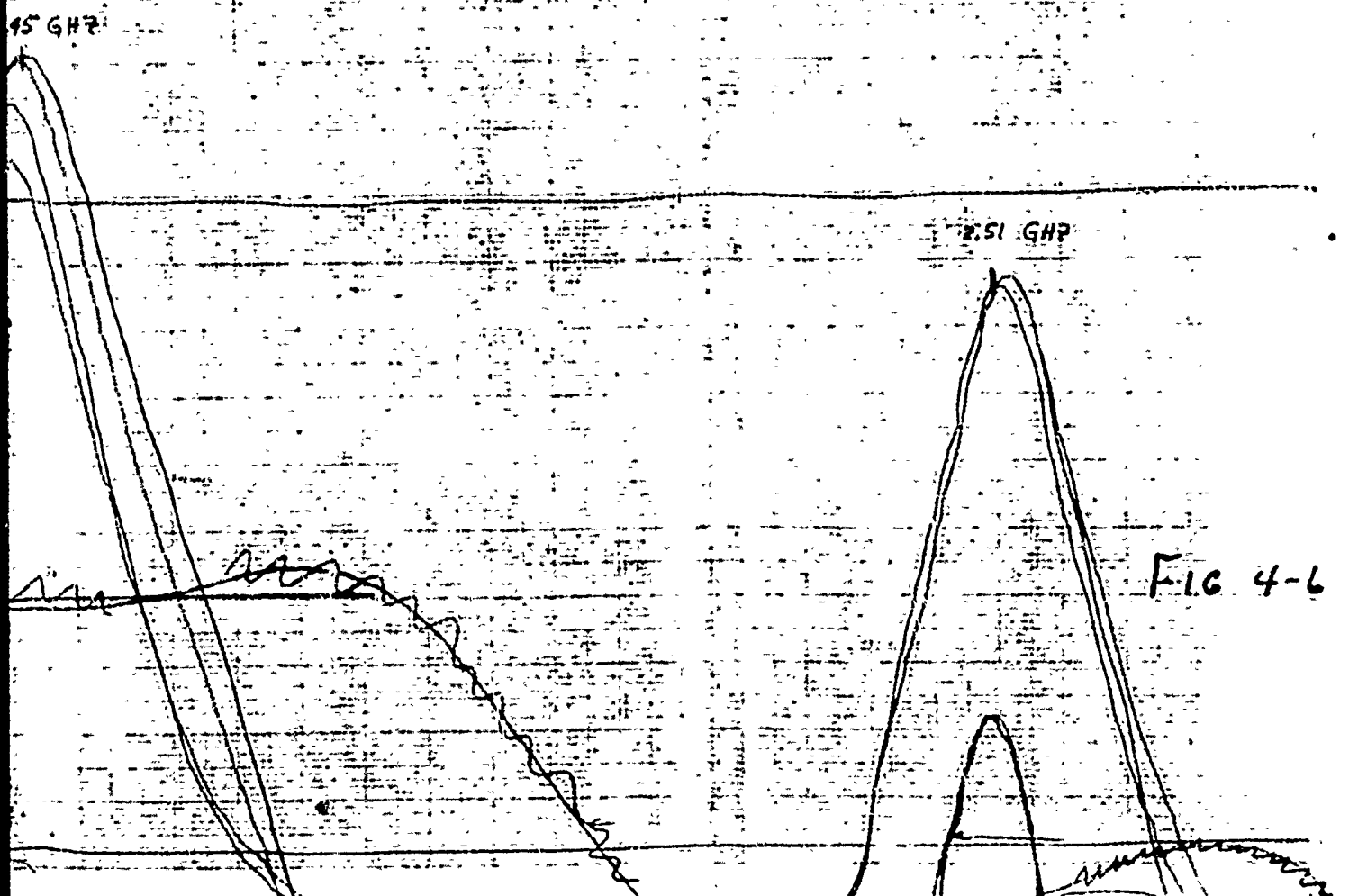
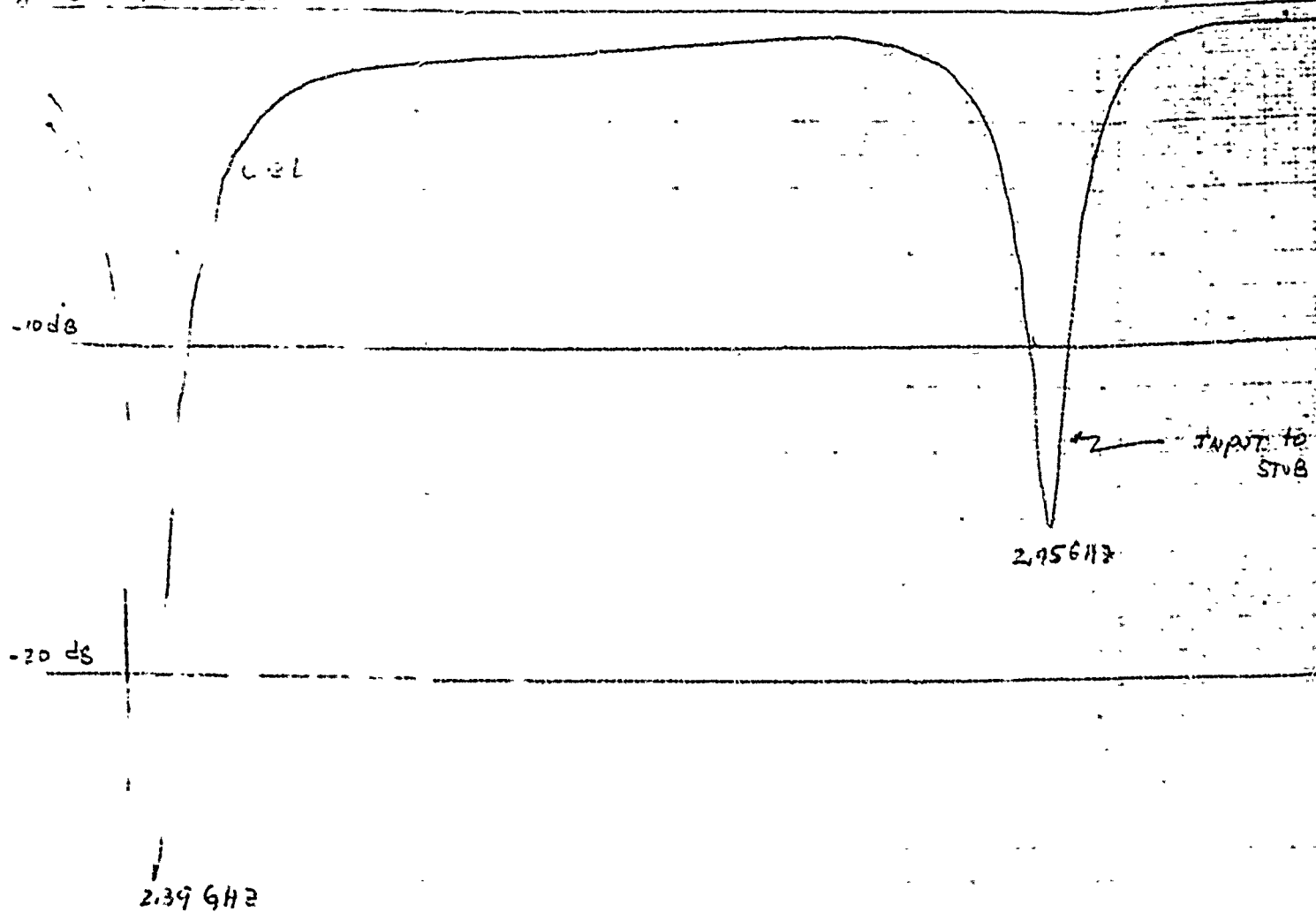


FIG 4-6

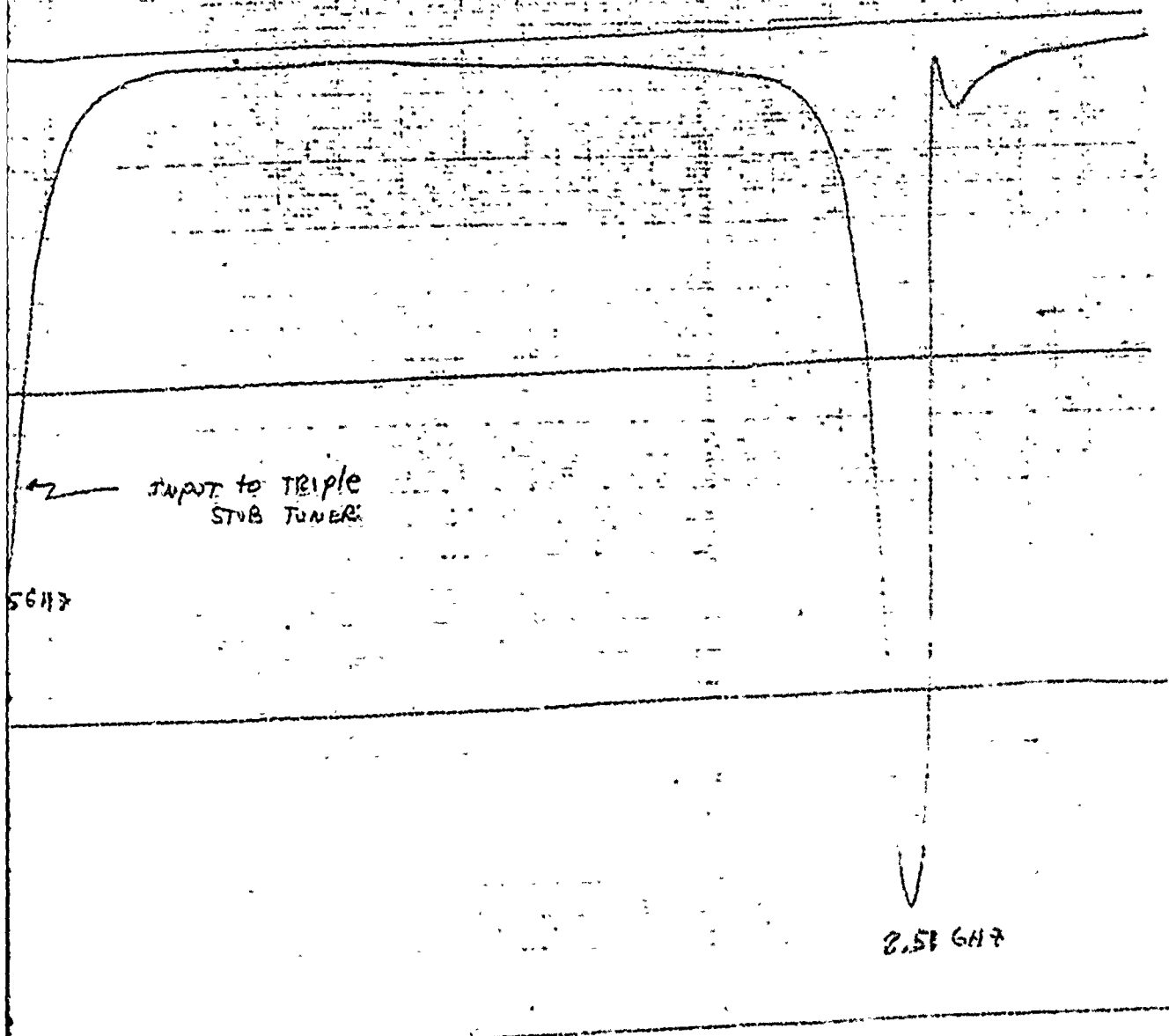
dB RETURN LOSS



-30 dB RETURN LOSS

4EG

11/3/80



RETURN LOSS

MODE	TE ₁₁ TRAVELING WAVE (ΔMOLE)
INPUT	WAVEGUIDE
OUTPUT	COAXIAL (POWER)
SHORT	3 REF, IN 1/4"
CAVITY	AIR
Comments	
POWER	1 mW
LEVEL	

FIG. 4-7

0 dB INSERTION LOSS

-10 dB

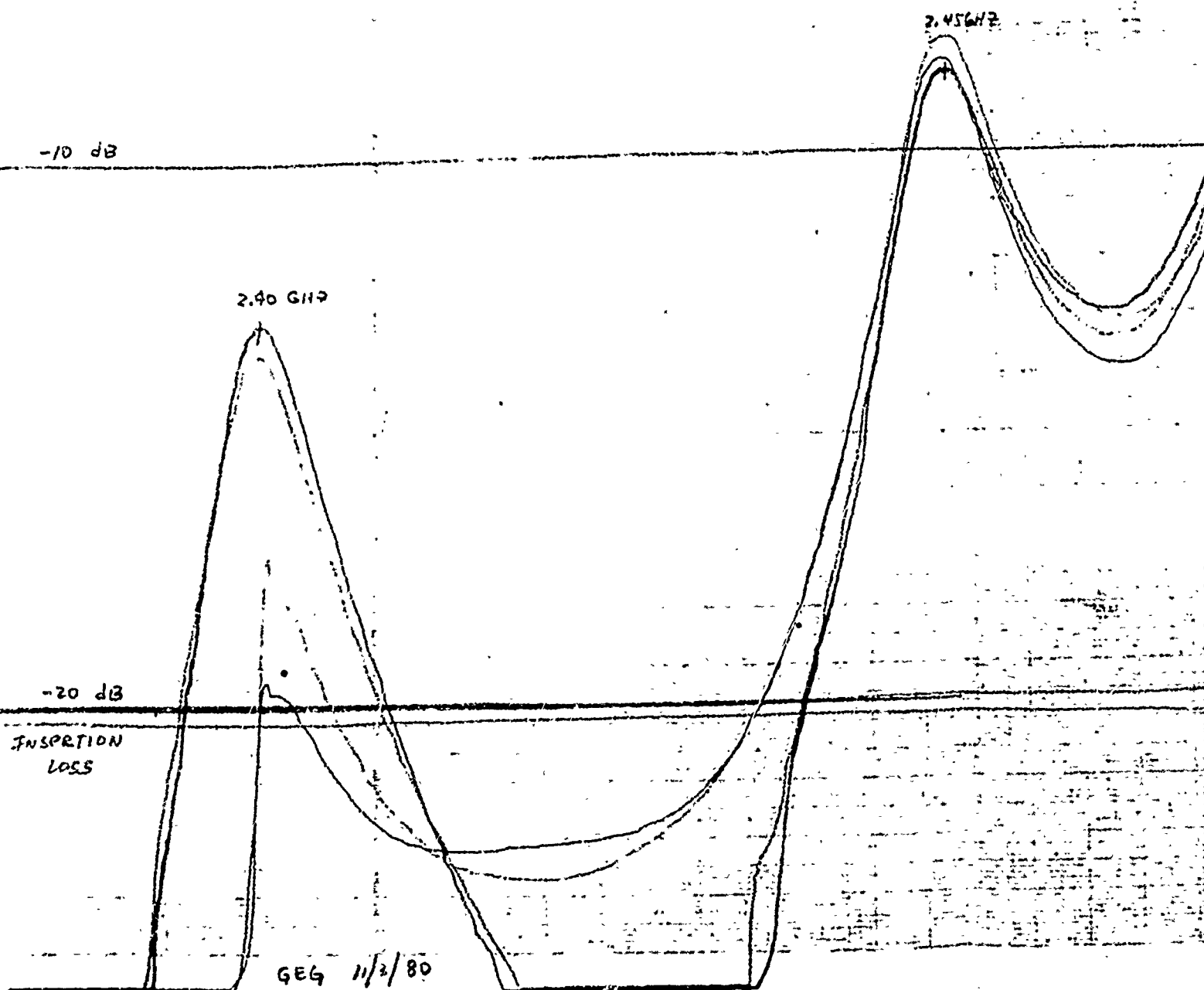
2.40 GHz

2.45 GHz

-20 dB

INSERTION
LOSS

GE4 11/3/80



#2 RED

#3 BLACK

BLUE
PROBE #1

GREEN
PROBE #4

FRONT VIEW



SIDE VIEW

INSERTION LOSS
MODE TMD: TRAVELING WAVE
INPUT WAVE GUIDE
OUTPUT COAXIAL (FOUR)
SHORT POSITION Z (SCALE)
Cavity Contacts AIR
POWER 10mw
LEVEL

2.47 GHz

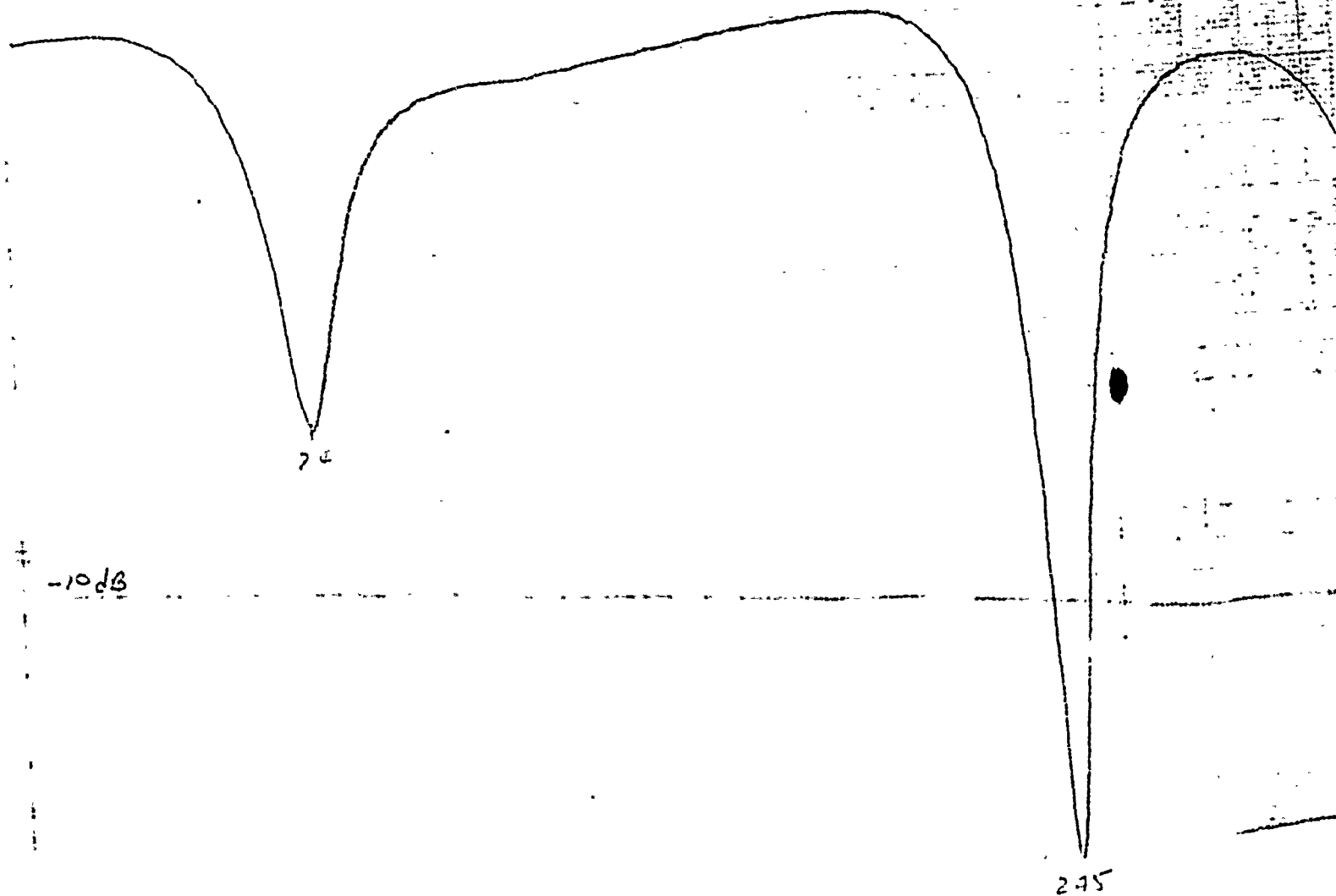
2.52 GHz

2.50 GHz

FIG. 4-8

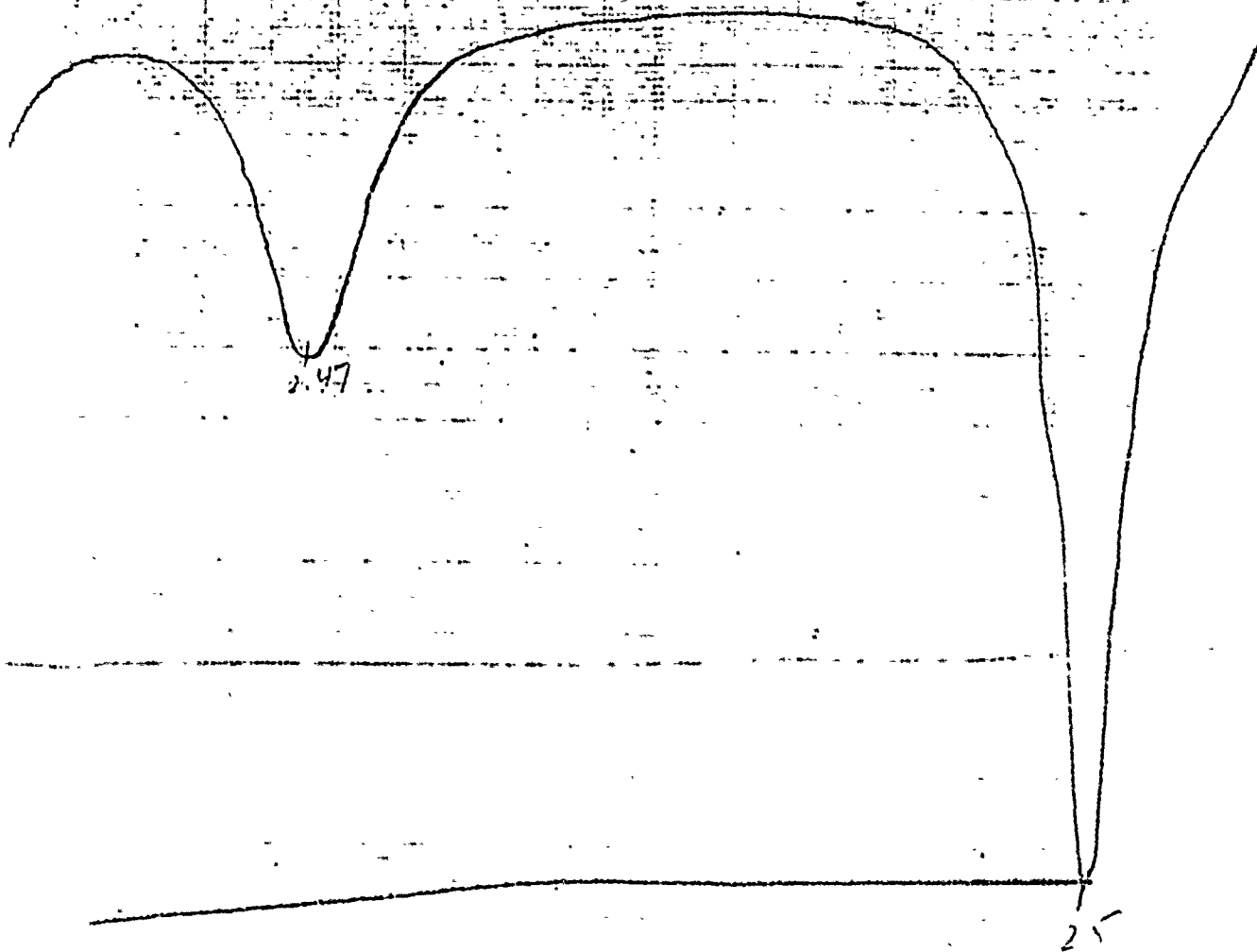
TR 01 E MODE

0 dB RETURN LOSS



-10dB

-20 dB RETURN LOSS



RETURN	LOSS	
MODE	TMOI	TRAVELING MODE
INPUT		

FIG 4-9

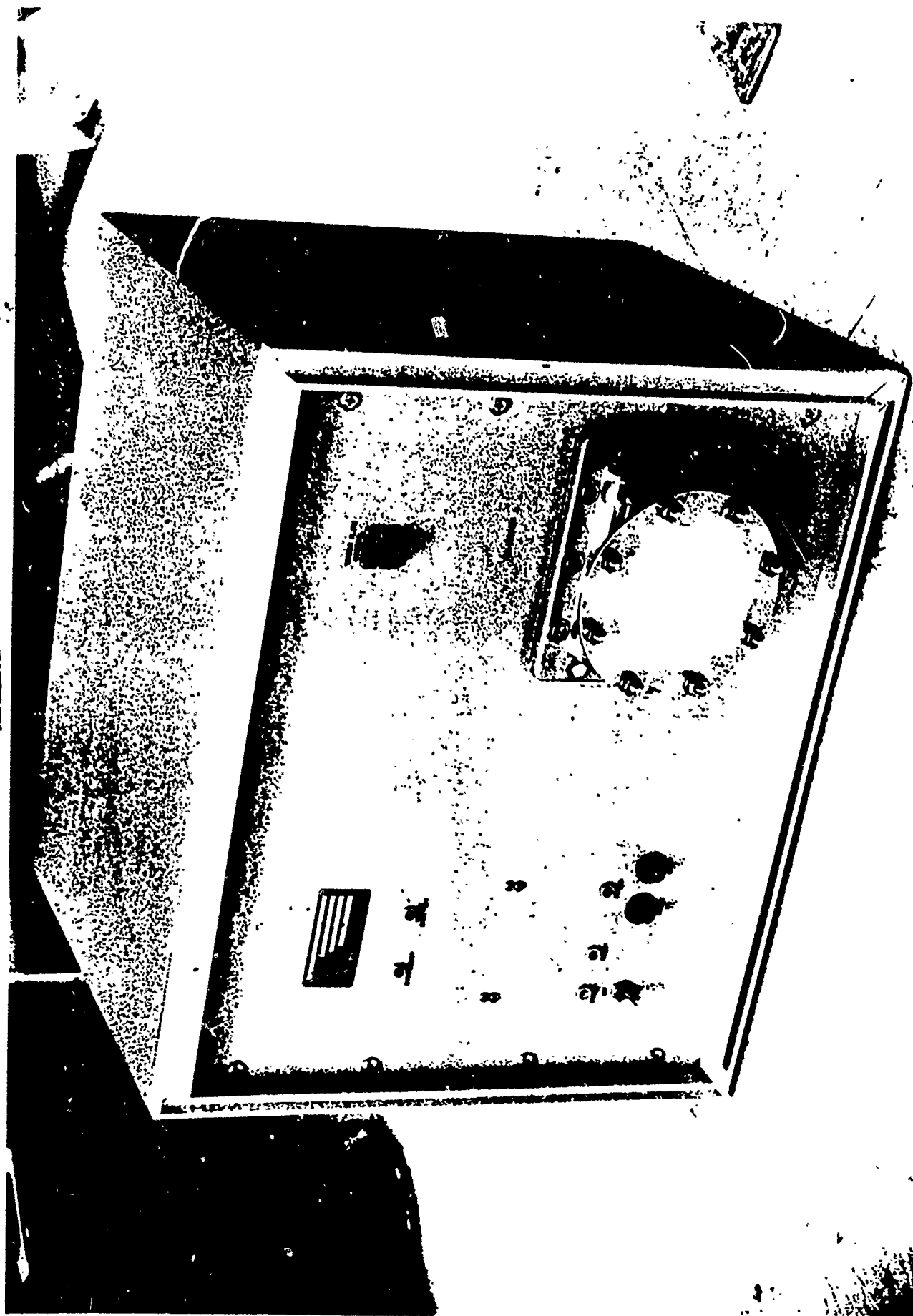
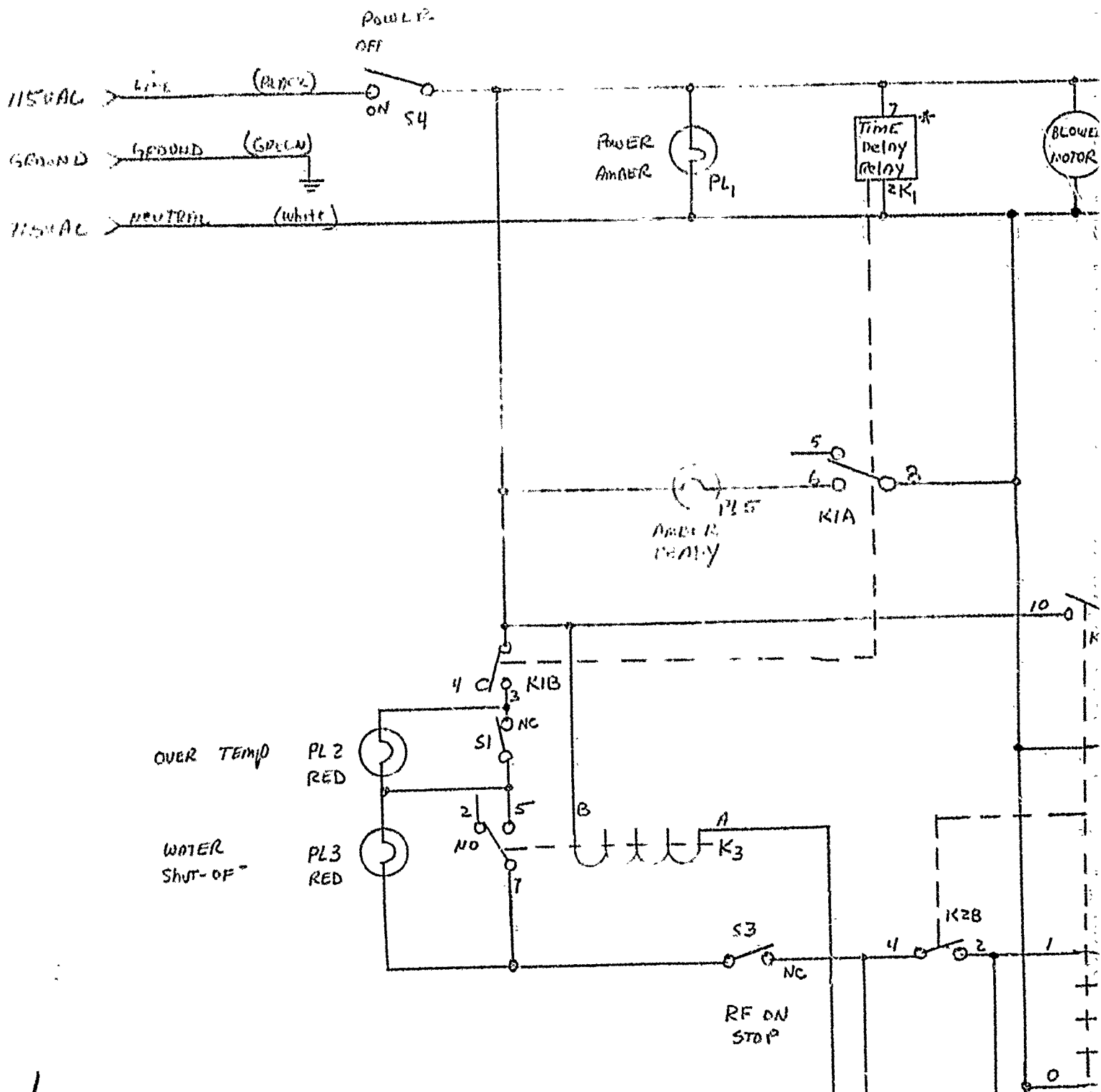


FIG 5 - PHOTO OF RF SOURCE



FORM

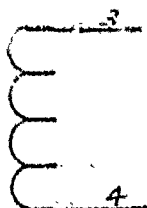
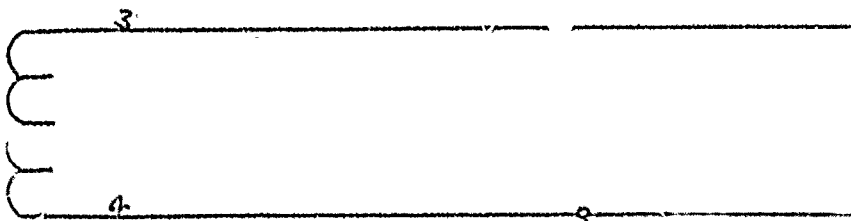
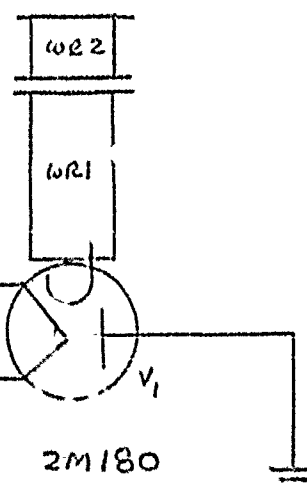
2

1

REVISIONS

ZONE	LTR	DESCRIPTION

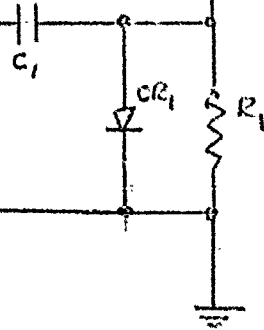
RF OUTPUT
WR 284 WAVEGUIDE



TP 1

TYPICAL OPERATION DATA

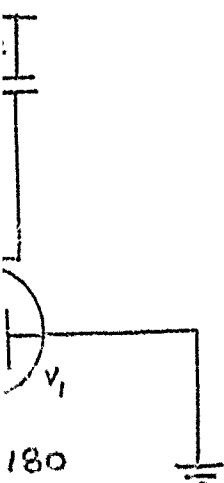
RF POWER OUTPUT	AVG. 1.07 KW
RF FREQ OUTPUT	2.45 GHz
ANODE VOLTAGE	AVG. 2.05 KVDC
ANODE CURRENT	AVG. 0.9 ADC
FILAMENT VOLTAGE	4.4 VAC
FILAMENT CURRENT	16 AAC
AC VOLTAGE INPUT	115 VAC
AC CURRENT INPUT	—



REVISIONS

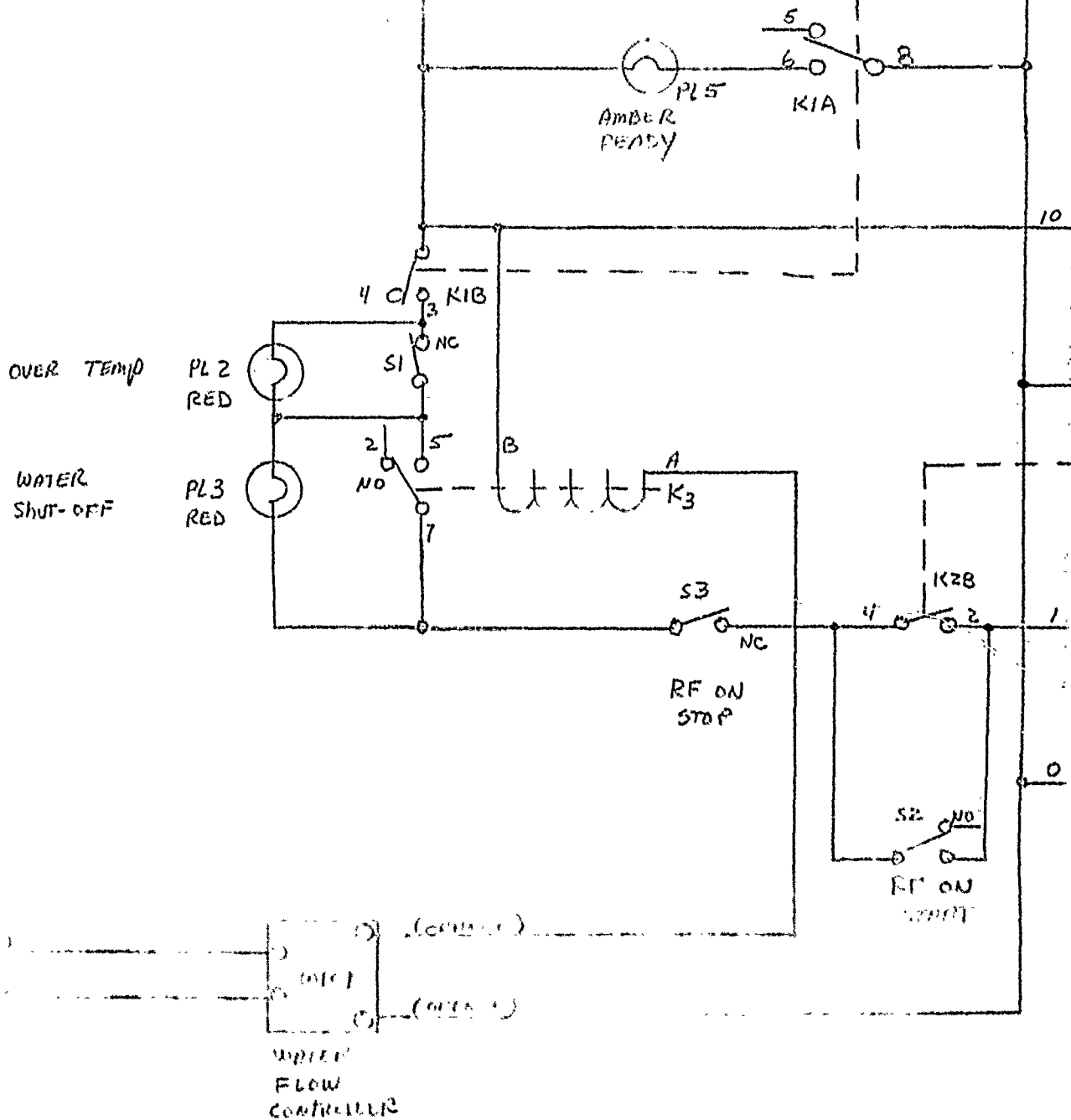
ZONE	LTR	DESCRIPTION	DATE	APPROVE

INPUT
BY WAVEGUIDE



TYPICAL OPERATION DATA

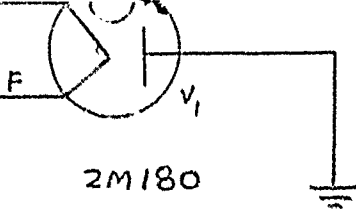
POWER OUTPUT AVG.	1.07 KW
FREQ OUTPUT	2.95 GHz
ODE VOLTAGE AVG.	2.05 KVDC
ODE CURRENT AVG.	0.9 ADC
ANODE VOLTAGE	4.4 VAC
ANODE CURRENT	16 AAC
VOLTAGE INPUT	115 VAC
CURRENT INPUT	---



ENGINEERING CHECK LIST

- SKETCHING ☐ LOCATE ON GRID. FREEHAND SKETCHING PREFERRED. LOCATE CIRCUIT SYMBOLS FUNCTIONALLY AROUND EACH STAGE. CONNECT STAGES IN LAYERS FROM LEFT-TO-RIGHT. ARRANGE TWO OR MORE LAYERS FROM TOP-TO-BOTTOM.
- SIGNAL FLOW ☐ LOCATE INPUTS AT LEFT, OUTPUTS AT RIGHT (PREFERRED); OR INPUTS AT TOP, OUTPUTS AT BOTTOM; OR ANY COMBINATION OF THE TWO ABOVE.
- SYMBOLS ☐ USE CIRCUIT SYMBOLS PER USA STD Y32.2 FOR DETAIL, SEE ENGINEERING STANDARDS MANUAL. USE LOGIC SYMBOLS PER USA STD Y32.13 FOR DETAIL, SEE ENGINEERING STANDARDS MANUAL.

- REF DESIG ☐ IDENTIFY EACH SYMBOL BY REFERENCE DESIGNATION PER USA STD Y32.16. FOR DETAIL SEE ESM. ASSIGN REF. DESIG NUMBERS CONSECUTIVELY FROM LEFT TO RIGHT IN FUNCTIONAL SEQUENCE.
- PARTS IDENT ☐ SPECIFY RESISTANCE, CAPACITANCE AND INDUCTANCE VALUES. USE THE FORM OF FEWEST CIPHERS. SCHEMATIC IDENTITIES MUST AGREE WITH ELECTRICAL PARTS LIST.
- OTHER INFO ☐ ASSIGN FUNCTIONAL IDENTIFICATION TO PARTS, STAGES AND CIRCUITS. INDICATE MECHANICAL LINKAGE, POT ADJUSTMENT AND OPERATING CONTROLS. INDICATE SHIELDING, PAIRING AND CRITICAL GROUND. OUTLINE TERMINAL BOARDS AND SUB ASSEMBLIES.



TYPICAL OPERATION DATA

RF POWER OUTPUT AVG.	1.1 KW
RF FREQ OUTPUT	2.45 GHz
ANODE VOLTAGE AVG.	2.05 KVDC
ANODE CURRENT AVG.	0.4 ADC
FILAMENT VOLTAGE	4.4 VAC
FILAMENT CURRENT	16 AAC
AC VOLTAGE INPUT	115 VAC
AC CURRENT INPUT	---

3

Wm. Doherty Kelly
 Date: 11/11/60
 Kelly 60520

PREPARED IN ACCORDANCE WITH MIL STD 100		CONTRACT <u>DDAK 76-19-C-517</u>		AVIONICS DIVISION		MUTLEY, NEW JERSEY	
APPROVALS SIGNATURE & DATE		DRAWN <u>[Signature]</u>		RF SOURCE FIG 6		6	
CHECKED		MECH					
ELECT		SALES					
E OF M		DATE					
APPLICATION		DATE					
SCALE		CATEGORY		SHEET		REV	

AVIONICS DIVISION		NUTLEY, NEW JERSEY		ELECTRICAL PARTS LIST				DRAWING NUMBER	
ASSY NAME: ASSY REF DESIG:		PART OF UNIT: RF SOURCE		PART OF EQUIP:					
1	2	3	4	5	6		7	8	
CIRCUIT REF DESIG	PART DESCRIPTION	VALUE & TOL	MFR OR MIL SPEC	MFR OR MIL PART NO. ITT PART NO.	STRESS		REL CODE IDENT	FAIL RATE %	
					RATED	APPLIED NOM MAX			
C1	CAPACITOR		LITTON	M10DS9					
CPI	DIODE, High VOLTAGE		LITTON	M3D29					
K1	RELAY, Time Delay		MAGNETICRAFT	W211ACPSOX-8					
K2	RELAY, POWER		LITTON	M16D61					
K3	RELAY		STRUTHERS-DUNN	A283XAXC1					
PL1	PILOT Light, AMBER		LEECRAFT	36EN2313					
PL2	PILOT Light, RED		LEECRAFT	36EN2311					
PL3	PILOT Light, RED		LEECRAFT	36EN2311					
PL4	PILOT Light, RED		LEECRAFT	36EN2311					
PL5	PILOT Light, AMBER		LEECRAFT	36EN2313					

PREPARED BY ENGINEERING		SIZE	CODE IDENT NO.	FIG. 7a	SHEET 1 OF 2	REV
APPROVED BY: RELIABILITY - ENGINEERING - <i>28527</i>		A	28527			

AVIONICS DIVISION		NUTLEY, NEW JERSEY		ELECTRICAL PARTS LIST				DRAWING NUMBER			
ASSY NAME: ASSY REF DESIG:		PART OF UNIT: UNIT OPER TEMP:		RF SOURCE		PART OF EQUIP:					
1	2	3	4	5	6	7	8				
CIRCUIT REF DESIG	PART DESCRIPTION	VALUE & TOL	MFR OR MIL SPEC	MFR OR MIL PART NO. ITT PART NO.	RATED	STRESS APPLIED NOM MAX	REL CODE IDENT	FAIL RATE %			
R1	RESISTOR, BLEEDER		LITTON	M3D12							
S1	SWITCH, THERMAL PROTECTION		LITTON	M4D77							
S2	SWITCH			MS25089-3C 828304							
S3	SWITCH			MS25089-3C 828304							
S4	CIRCUIT BREAKER	25 AMP	BOTTER & BROOKFIELD	112-2725-101							
T1	TRANSFORMER, FILAMENT		LITTON	M60D75							
T2	TRANSFORMER, HIGH VOLTAGE		LITTON	M60D53							
V1	TUBE, MAGNETRON		PANASONIC	2M180							
W1	WATER FLOW CONTROLLER		PRESSURE CONTROL	F103							

PREPARED BY ENGINEERING

SIZE

CODE IDENT NO.

APPROVED BY:

RELIABILITY -

ENGINEERING - 98 2-10-70

A

28527

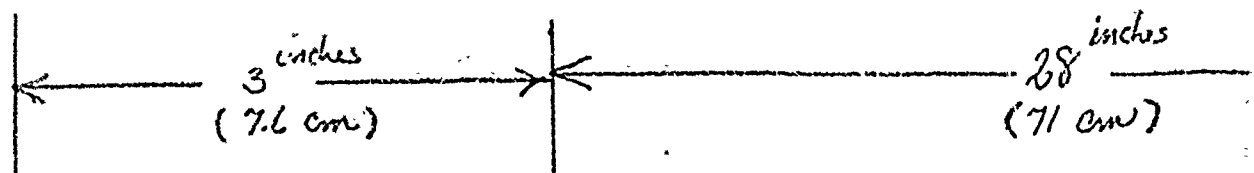
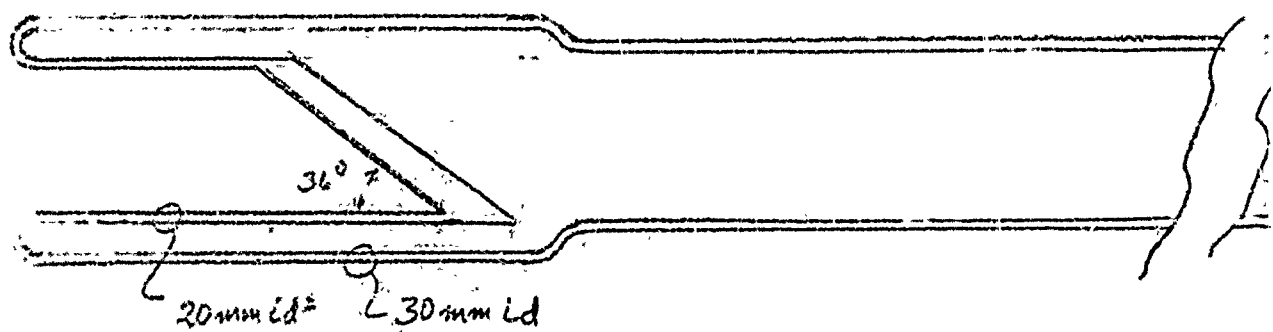
FIG. 7b

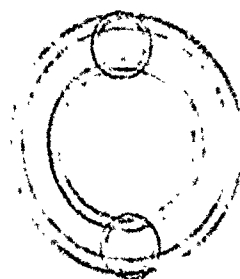
SHEET 2 OF 3

REV

Mode	Cavity Contents	Short Position (inches)	Incident Power (watts)	Reflected Power (watts)	Isolated Port (watts)	Power Dissipated In Cavity (watts)
TE-11	Pyrex	4-3/4	1278	40	209	1029
TE-11	Quartz & Carbon	2	1178	89	225	864
TM-01	Empty	4-7/8	1120	186	649	285
TM-01	Pyrex	2-5/16	1266	64	94	1108

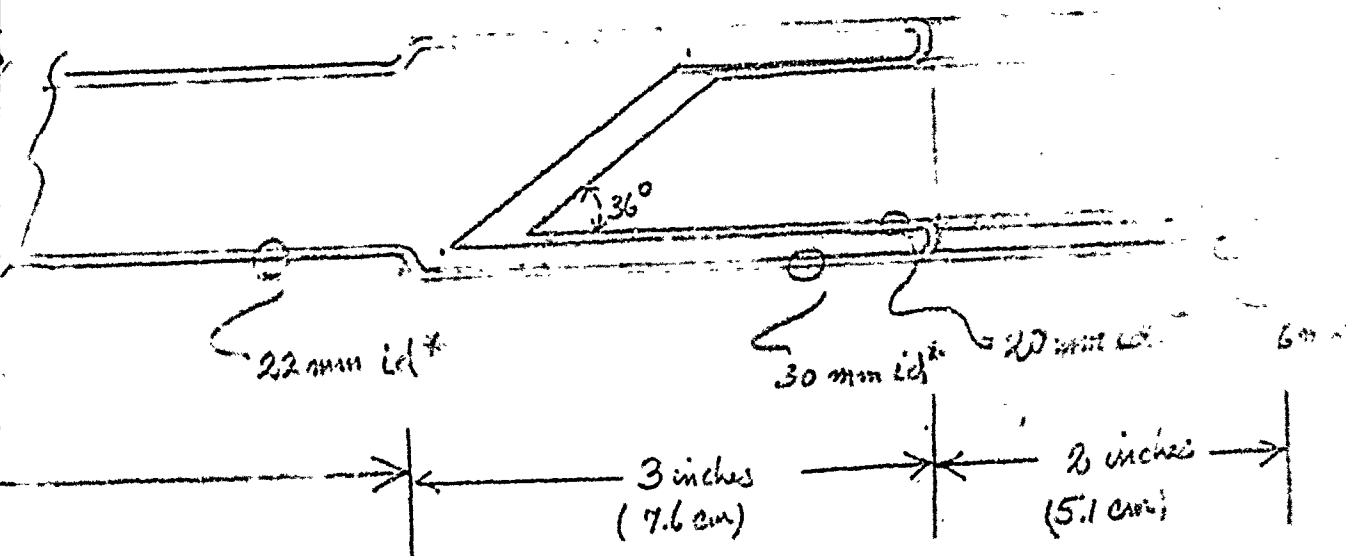
FIGURE 4-10 Summary of High Power Measurements





Section A

A



* Material: Alcoa fused Quartz tubing G. 8565.
Single Bore Standard wall.

Window Thickness 5 mm. Laser grade Quartz.

APPENDIX II

A PROGRAM FOR THE SOLUTION OF SAHA'S EQUATION

$$\log_{10} \left(\frac{\epsilon^2}{1 - \epsilon^2} \right) \times P = -5044 \frac{E}{T} + \log_{10} \frac{\omega_i \omega_e}{\omega_a} - 6.491$$

Program For Saha's Equation

000	43	RCL
001	01	01
002	99	PRT
003	43	RCL
004	07	07
005	99	PRT
006	98	HDV
007	43	RCL
008	02	02
009	99	PRT
010	43	RCL
011	12	12
012	65	X
013	43	RCL
014	13	13
015	55	+
016	43	RCL
017	14	14
018	95	=
019	42	STD
020	05	05
021	43	RCL
022	03	03
023	65	X
024	43	RCL
025	01	01
026	55	+
027	43	RCL
028	02	02
029	95	=
030	42	STD
031	08	08
032	43	RCL
033	04	04
034	65	X
035	53	(
036	43	RCL
037	02	02
038	28	LDG
039	54)
040	95	=
041	42	STD
042	09	09
043	43	RCL
044	05	05
045	28	LDG
046	95	=
047	42	STD
048	10	10
049	43	RCL
050	07	07
051	28	LDG
052	95	=
053	42	STD
054	08	08
055	43	RCL
056	08	08
057	94	+/-
058	85	+
059	43	RCL
060	09	09
061	85	+
062	43	RCL
063	10	10
064	75	-
065	43	RCL
066	06	06
067	75	-
068	43	RCL
069	11	11
070	54)
071	22	INV
072	28	LDG
073	95	=
074	42	STD
075	15	15
076	53	(
077	43	RCL
078	15	15
079	55	+
080	53	(
081	01	1
082	85	+
083	43	RCL
084	15	15
085	54)
086	54)
087	34	EX
088	95	=
089	42	STD
090	16	16
091	99	PRT
092	01	1
093	75	-
094	43	RCL
095	16	16
096	95	=
097	99	PRT
098	53	(
099	43	RCL
100	07	07
101	28	LDG
102	75	-
103	43	RCL
104	19	19
105	75	-
106	43	RCL
107	02	02
108	42	STD
109	07	07
110	43	RCL
111	18	18
112	75	-
113	43	RCL
114	20	20
115	54)
116	22	INV
117	28	LDG
118	95	=
119	42	STD
120	21	21
121	65	X
122	43	RCL
123	16	16
124	95	=
125	42	STD
126	22	22
127	99	PRT
128	98	HDV
129	69	DP
130	20	20
131	43	RCL
132	00	00
133	65	X
134	43	RCL
135	17	17
136	95	=
137	42	STD
138	02	02
139	61	GTG
140	00	00
141	07	07
142	07	07

Data Base

2.4	01	00
7.4336392	-05	01
2.4	03	02
5.044	03	03
2.5	00	04
1.	00	05
6.491	00	06
1.	-03	07
2.1930435	01	08
8.4043196	00	09
0.	00	10
-3.	00	11
1.	00	12
2.	00	13
2.	00	14
9.6135725	-18	15
3.1005762	-09	16
1.	02	17
-2.3779957	01	18
1.9141	00	19
0.	00	20
3.1924896	15	21
9.858557	06	22

DATA OUTPUT

7.4336392-05 EV ionization
1.-03 RTMOS

2.4 03 • Kelvin
9.9999451-01 I-E
5.490281-06 e
3.0594524 15 m_ecm³

2.5 03

APPENDIX III

A PROGRAM FOR DETERMINING THE PARAMETERS OF A CYLINDER WAVE GUIDE

CAVITY USING THE TI59 HAND COMPUTER

The parameters of a cylinder wave guide cavity may be calculated from the materials and geometry that make up the cavity. A program has been written that is suitable for a TI 59 hand computer that is equipped with a printer. The notation is defined for the parameters in the tabulation of the storage positions.

Table 3.1 below.

The relationships are those used in the MIT Radiation Laboratory series particularly Vol 11 Section 5.4 Vol. 8 Section 11.

The interrelations are:

Table 3.1

$$\epsilon_1 = \epsilon' - j\epsilon'' \quad ; \quad \epsilon_1/\epsilon_0 = \epsilon'/\epsilon_0 - j\epsilon''/\epsilon_0 \quad \text{for } \mu_1/\mu_0 = 1$$

$$(\epsilon_0/\epsilon_1)^{1/2} c = v \text{ (phase velocity)} = \lambda_1 f_0 \quad ; \quad c = \lambda_0 f_0$$

$$\lambda_c = \frac{\pi D}{x_{1m}} (\epsilon'/\epsilon_0)^{1/2} \quad ; \quad S = \left(\frac{\lambda_0 \rho}{30} \right)^{1/2} / 2\pi$$

$$\lambda_g/\lambda_0 = \left[\left(\epsilon_1/\epsilon_0 - (\lambda_0/\lambda_{c0})^2 \right) \times \left(1 + \left(1 + \left(\frac{\epsilon''/\epsilon_0}{\epsilon_1/\epsilon_0 - (\lambda_0/\lambda_{c0})^2} \right)^2 \right)^{1/2} \right) / 2 \right]^{-1/2}$$

$$L = n/2 / \left((1/\lambda^2) - (x_{lm}/\pi D)^2 \right)^{1/2}$$

$$Q S/\lambda_1 = \frac{\left[1 - (\rho/x_{lm})^2 \right] \times \left[x_{lm}^2 + (n\pi D/2L)^2 \right]^{3/2}}{2\pi \left[x_{lm}^2 + n^2 \pi^2 D^3/4L^3 + (1-D/L) (n\pi D \rho/2L x_{lm})^2 \right]}$$

Table 3.2

DATA STORAGE POSITIONS FOR CYLINDRICAL WAVE GUIDE CAVITY PROGRAM

Stor

- 01 f_0 frequency Hz
- 02 D diameter cm
- 03 L length cm
- 04 ρ resistivity of cavity material ohm cm
- 05 ϵ^1/ϵ_0 real part of the dielectric constant relative to vacuum
- 06 ϵ^{11}/ϵ_0 imaginary part of the dielectric constant relative to vacuum
- 07 L/D ratio of the length to diameter of chamber
- 08 λ_0 vacuum wavelength, cm, resulting from applied frequency f_0
- 09 δ skin depth of the cavity wall, cm
- 10 c the velocity of light space, cm/sec
- 11 $120\pi^2$ a constant
- 12 x_{1m}^{mth} Root of the bessel function $J_1'(x) = 0$ TE mode
- 13 λ_{co} cutoff wavelength for TE mode in a vacuum cavity, cm
- 14 λ_q wavelength in guide of TE mode in an ϵ_0 filled cavity, cm
- 15 α_d attenuation coefficient due to dielectric losses cm^{-1}
- 16 n the length of the cavity in $\frac{1}{2}$ periods of E_r
- 19 x_{1m}^{mth} Root of bessel function $J_1(x) = 0$ TM mode
- 20 λ_{co} cutoff wavelength of TM mode in a vacuum cavity 1 cm
- 25 $(\epsilon_0/\mu_0)^{\frac{1}{2}}$
- 26 $(\lambda_0/\lambda_{co})^2$ TE mode
- 27 λ_1 wavelength in a medium ϵ_1/ϵ_0 due to f_0 , (cm)
- 28 TE, λ_c cutoff wavelength in an ϵ/ϵ_0 filled TE cavity

Stor (cont'd)

- 29 1 the number of full period variations of E_r as a function of θ
- 30 $(n\pi D/2L)^2$ for TE cavities
- 31 $Q \delta/\lambda_1$ the geometrically dependent component of the cavity
quality for the TE mode.
- 32 Q the quality factor for the TE modes.
- 33 λ_{co} the cutoff wavelength for an ϵ/ϵ_0 filled TM cavity cm
- 34 $(\lambda_0/\lambda_{co})^2$ TM mode
- 35 λ_g the angular wavelength for the TM mode cm
- 36 α_d the dielectric attenuation in the TM mode cm^{-1}
- 37 L the length of the TM cavity cm
- 38 L/D the length to diameter ratio of the TM cavity
- 39 $(n\pi D/2L)^2$ for TM cavities
- 40 $Q \delta/\lambda$ the geometrically dependent component of the cavity
quality for the TM modes.
- 41 Q the quality of the TM mode cavities.

000	25	CLR
001	69	DP
002	00	00
003	04	4
004	03	3
005	01	1
006	03	3
007	04	4
008	02	2
009	01	1
010	07	7
011	00	0
012	00	0
013	69	DP
014	01	01
015	02	2
016	02	2
017	04	4
018	01	1
019	02	2
020	04	4
021	01	1
022	06	6
023	01	1
024	07	7
025	69	DP
026	02	02
027	00	0
028	00	0
029	01	1
030	05	5
031	01	1
032	03	3
033	04	4
034	02	2
035	02	2
036	04	4
037	69	DP
038	03	03
039	03	3
040	07	7
041	04	4
042	05	5
043	00	0
044	00	0
045	00	0
046	00	0
047	00	0
048	00	0
049	69	DP
050	04	04
051	69	DP
052	05	05
053	43	RCL
054	01	01
055	99	PRT
056	43	RCL
057	02	02
058	99	PRT
059	43	RCL
060	03	03
061	43	RCL
062	04	04
063	99	PRT
064	43	RCL
065	05	05
066	99	PRT
067	43	RCL
068	06	06
069	99	PRT
070	43	RCL
071	10	10
072	55	÷
073	43	RCL
074	01	01
075	95	=
076	42	STD
077	08	08
078	99	PRT
079	43	RCL
080	08	08
081	55	÷
082	43	RCL
083	05	05
084	34	FX
085	95	=
086	42	STD
087	27	27
088	99	PRT
089	53	(
090	43	RCL
091	08	08
092	65	x
093	43	RCL
094	04	04
095	55	÷
096	43	RCL
097	11	11
098	54)
099	34	FX
100	95	=
101	42	STD
102	09	09
103	99	PRT
104	98	ADV
105	69	DP
106	00	00
107	03	3
108	07	7
109	01	1
110	07	7
111	00	0
112	02	2
113	00	0
114	02	2
115	00	0
116	00	0
117	69	DP
118	02	02
119	69	DP
120	05	05
121	89	n
122	65	x
123	43	RCL
124	02	02
125	55	÷
126	43	RCL
127	12	12
128	99	PRT
129	95	=
130	95	=
131	42	STD
132	13	13
133	99	PRT
134	43	RCL
135	05	05
136	34	FX
137	65	x
138	43	RCL
139	13	13
140	95	=
141	42	STD
142	28	28
143	99	PRT
144	53	(
145	43	RCL
146	08	08
147	55	÷
148	43	RCL
149	13	13
150	54)
151	33	X²
152	95	=
153	42	STD
154	26	26
155	43	RCL
156		

217	16	16	277	33	X ²	337	65	X	397	65	X
218	55	÷	278	54	)	338	43	RCL	398	53	(
219	53	(	279	65	X	339	27	27	399	53	(
220	02	2	280	53	(	340	55	÷	400	43	RCL
221	65	X	281	43	RCL	341	43	RCL	401	05	05
222	53	(	282	12	12	342	09	09	402	75	-
223	43	RCL	283	33	X ²	343	95	=	403	43	RCL
224	27	27	284	85	+	344	42	STD	404	34	34
225	33	X ²	285	43	RCL	345	32	32	405	54)
226	35	1/X	286	30	30	346	99	PRT	406	65	X
227	75	-	287	54	)	347	98	ADV	407	53	(
228	43	RCL	288	45	YX	348	69	DP	408	01	1
229	13	13	289	01	1	349	00	00	409	85	+
230	33	X ²	290	93	.	350	03	3	410	53	(
231	35	1/X	291	05	5	351	07	7	411	01	1
232	54	)	292	54	)	352	03	3	412	85	+
233	34	FX	293	55	÷	353	00	0	413	53	(
234	54	)	294	53	(	354	00	0	414	43	RCL
235	95	=	295	02	2	355	01	1	415	06	06
236	42	STD	296	65	X	356	00	0	416	55	÷
237	03	03	297	89	π	357	02	2	417	53	(
238	99	PRT	298	65	X	358	00	0	418	43	RCL
239	43	RCL	299	53	(	359	00	0	420	75	-
240	03	03	300	43	RCL	360	69	DP	420	65	X
241	55	÷	301	12	12	361	02	02	421	43	RCL
242	43	RCL	302	33	X ²	362	69	DP	422	34	34
243	02	02	303	85	+	363	05	05	423	54)
244	95	=	304	43	RCL	364	43	RCL	424	54)
245	42	STD	305	30	30	365	02	02	425	33	X ²
246	07	07	306	55	÷	366	65	X	426	54)
247	99	PRT	307	43	RCL	367	89	π	427	34	FX
248	98	ADV	308	07	07	368	55	÷	428	54)
249	53	(	309	85	+	369	43	RCL	429	55	÷
250	43	RCL	310	53	(	370	19	19	430	02	2
251	16	16	311	01	1	371	99	PRT	431	54)
252	65	X	312	75	-	372	95	=	432	34	FX
253	89	π	313	43	RCL	373	42	STD	433	35	1/X
254	55	÷	314	07	07	374	20	20	434	95	=
255	53	(	315	35	1/X	375	99	PRT	435	42	STD
256	02	2	316	54	)	376	65	X	436	35	35
257	65	X	317	65	X	377	43	RCL	437	99	PRT
258	43	RCL	318	53	(	378	05	05	438	43	RCL
259	07	07	319	43	RCL	379	33	X ²	439	35	35
260	54	)	320	30	30	380	95	=	440	65	X
261	54	)	321	65	X	381	42	STD	441	43	RCL
262	33	X ²	322	53	(	382	33	33	442	06	06
263	95	=	323	43	RCL	383	99	PRT	443	65	X
264	42	STD	324	29	29	384	53	(	444	89	π
265	30	30	325	55	÷	385	43	RCL	445	55	÷
266	53	(	326	43	RCL	386	08	08	446	43	RCL
267	53	(	327	12	12	387	55	÷	447	08	08
268	01	1	328	54	)	388	43	RCL	448	33	X ²
269	75	-	329	33	X ²	389	20	20	449	95	=
270	53	(	330	54	)	390	54	)	450	42	STD
271	43	RCL	331	95	=	391	33	X ²	451	36	36
272	29	29	332	42	STD	392	95	=	452	99	PRT
273	55	÷	333	31	31	393	42	STD	453	43	RCL
274	43	RCL	334	99	PRT	394	34	34	454	16	16
275	12	12	335	43	RCL	395	43	RCL	455	99	PRT
276	54	)	336	31	31	396	08	08	456	55	÷

457	53	(	517	89	π
458	02	2	518	65	X
459	65	X	519	53	(
460	53	(	520	01	1
461	43	RCL	521	85	+
462	27	27	522	43	RCL
463	33	X ²	523	38	38
464	35	1/X	524	35	1/X
465	75	-	525	54)
466	43	RCL	526	54)
467	20	20	527	95	=
468	33	X ²	528	42	STD
469	35	1/X	529	40	40
470	54	)	530	99	PRT
471	34	π X	531	65	X
472	54	)	532	43	RCL
473	95	=	533	27	27
474	42	STD	534	55	+
475	37	37	535	43	RCL
476	99	PRT	536	09	09
477	43	RCL	537	95	=
478	37	37	538	42	STD
479	55	+	539	41	41
480	43	RCL	540	99	PRT
481	02	02	541	98	ADV
482	95	=	542	91	R/S
483	42	STD	543	61	GTD
484	38	38	544	01	01
485	99	PRT	545	05	05
486	98	ADV	546	91	R/S
487	53	(
488	43	RCL			
489	16	16			
490	65	X			
491	89	π			
492	55	+			
493	-	(
494	02	2			
495	65	X			
496	43	RCL			
497	38	38			
498	54)			
499	54)			
500	33	X ²			
501	95	=			
502	42	STD			
503	39	39			
504	53	(
505	43	RCL			
506	19	19			
507	33	X ²			
508	85	+			
509	43	RCL			
510	39	39			
511	54)			
512	34	π			
513	55	+			
514	53	(
515	02	2			
516	65	X			

Table 3.3

PRINT OUT

WAVE GUIDE CAVITY	
2450000000.	f ₀
10.8402	D
.0000063694	ρ
1.	ϵ'/ϵ_0
0.	ϵ''/ϵ_0
12.23636735	λ_0
12.23636735	λ_1
.0002565287	δ
TE11	
1.841	x ₁₁
18.49836648	λ_{co}
18.49836648	λ_c
16.31603604	λ_g
0.	α_d
1.	n
8.15801802	L
.7525708031	L/D
TM01	
2.405	x ₀₁
14.16028802	λ_{co}
14.16028802	λ_c
24.31400837	λ_g
0.	α_d
1.	n
12.15700418	L
1.121474159	L/D
Q ₀ /λ ₁	
.2762474574	Q
13176.94899	
Q ₀ /λ ₁	
.2341565538	Q
11169.22123	

The computer instruction are given for a partition of 559.49 i.e. 49 data registers are allocated to information storage. Table 3.2 indicates the instructions required. Table 3.3 is a printout of the program solution that is used in section //.

APPENDIX IV

T159 Plasma Resistivity Program

Program

000	43	RCL	051	10	10
001	00	00	052	23	LNK
002	99	PRT	053	95	=
003	43	RCL	054	42	STD
004	01	01	055	11	11
005	99	PRT	056	99	PRT
006	53	(	057	43	RCL
007	53	(	058	11	11
008	53	(	059	65	x
009	43	RCL	060	43	RCL
010	05	05	061	06	06
011	65	x	062	55	+
012	43	RCL	063	53	(
013	00	00	064	43	RCL
014	54	)	065	00	00
015	45	YX	066	45	YX
016	03	3	067	01	1
017	54	)	068	93	.
018	55	+	069	05	5
019	53	(	070	54)
020	89	#	071	95	=
021	65	x	072	42	STD
022	43	RCL	073	12	12
023	01	01	074	99	PRT
024	54	)	075	98	ADV
025	54	)	076	91	R/S
026	34	FX	077	81	RST
027	65	x			
028	01	1			
029	95	.			
030	05	5			
031	55	+			
032	53	(
033	43	RCL			
034	03	03			
035	65	x			
036	43	RCL			
037	04	04			
038	65	x			
039	53	(
040	43	RCL			
041	02	02			
042	45	YX			
043	03	3			
044	54)			
045	54)			
046	95	=			
047	42	STD			
048	10	10			
049	99	PRT			
050	43	RCL			

Data File

	7. 03	00
	1. 11	01
4.80217-10		02
	1. 00	03
	1. 00	04
1.38024-16		05
	6.53 03	06
	0. 00	07
	0. 00	08
	0. 00	09
2.2950001	04	10
1.0041073	01	11
1.1195571-01		12

Output

7. 03	T °K
1. 11	$\eta_e \text{ cm}^{-1}$
2.2950001 04	Δ
1.0041073 01	$\ln \Delta$
1.1195571-01	ρ_{ohmic}